ANH
AGENCIA NACIONAL DE **HIDROCARBUROS**

Colombian Sedimentary Basins:

Nomenclature, Boundaries and Petroleum Geology, a New Proposal

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Línea Gratuita Nacional 018000 953 000

ISBN: 978-958-98237-0-5

Edited and compiled by: ANH and B&M Exploration Ltda.

Printed in Bogotá-Colombia

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MISSION

- The ANH is the agency responsible for promoting the optimal exploitation of the country's hydrocarbons resources, by managing them integrally and finding a balance between the interests of the State, Colombian society and companies operating in the sector.

VISION

The ANH will be recognized as a world model institution because of:

- Its knowledge of the Colombian sub-surface potential and the maximization of its exploitation;
- The efficiency in the management of hydrocarbons and the joint work with both industry and the community; and
- The professionalism of its team, a high technological level and its efficiency and flexibility in key processes.

FUNCTION

- Manage the nation's hydrocarbons areas and assign them for exploration and production. Assess the country's hydrocarbons potential.
- Sign and manage new hydrocarbons exploration and exploitation contracts.
- Design, evaluate and carry out strategies for the promotion of the country's hydrocarbons areas.
- Support the Ministry of Mines and Energy in the formulation of government policy for the sector.
- Manage and preserve technical information, both currently existing and acquired in the future.
- Negotiate, as part of the contracts, the terms and conditions of programs that will be carried out by the contractors in benefit of communities in the areas of influence of the contracts.
- Manage the State's share in exploration and exploitation contracts.
- Manage and dispose of the assets that become property of the State when concessions finish or revert.
- Collect royalties and financial resources that belong to the State for the exploitation of hydrocarbons, and make payments to entities entitled to those resources.
- Retain the sums corresponding to shares and royalties that belong to participating entities, which are channeled to the Petroleum Savings and Stabilization Fund (FAEP), and arrange the corresponding drafts and refunds.
- Undertake necessary steps to ensure an adequate supply of hydrocarbons, derivates and products, to meet national demand.
- Fix oil production levels in concession that exploiters must sell for domestic refining.
- Fix the price for crude oil in concession sold for domestic refining, processing or for use within de country, as well as for natural gas effectively used as raw material in petrochemical industrial processes, when necessary.
- Carry out all other activities in relation with the management of hydrocarbons owned by the nation, as well as those established by law or regulations, in line with the Agency's mandate.
- Decree 1760 has more detailed information about Ecopetrol's restructuring and the organizational structure of the National Hydrocarbons Agency.

GENERAL INFORMATION ABOUT COLOMBIA

Geographic Location

The Republic of Colombia is strategically located in the north-western corner or South America, with an area of 1.14 million square kilometers. It is the only South American country with two coasts, the Pacific (1,300 km) and the Atlantic (1,600 km) (figure 1).

Climate

Colombia's diverse topography produces a variety of climates, ranging from hot to perpetual snows. In general, the coastal and Amazonian areas are warm and tropical, while the mountainous terrain in the center of the country is cool throughout the year.

Population and Language

The population was almost 42 million in 2005, with 75% concentrated in urban centers and growing at 2.21% a year (http://www.dane.gov.co/censo/). There are more than 33 towns with over 100,000 inhabitants each. The official language is Spanish but English is widely used in business circles.

Type of Government

Colombia is a democratic republic with a President heading the executive branch, and a legislative branch made up by the Senate and the House of Representatives, with 112 and 199 members respectively. All are elected by popular vote for a four-year period.

2006 Economic Indicators

GNP per capita US$ 3.083

Annual Inflation 4.48%

Foreign Investment MUSS 6000

Growth Intern Brute Product 5.96%

Main Imports

Machinery, chemicals, metals, transport equipment, minerals, plastics and papers.

Main Exports

Oil, coal, nickel, coffee, bananas, flowers, cotton, sugar, fruits, minerals, chemicals, and textiles.

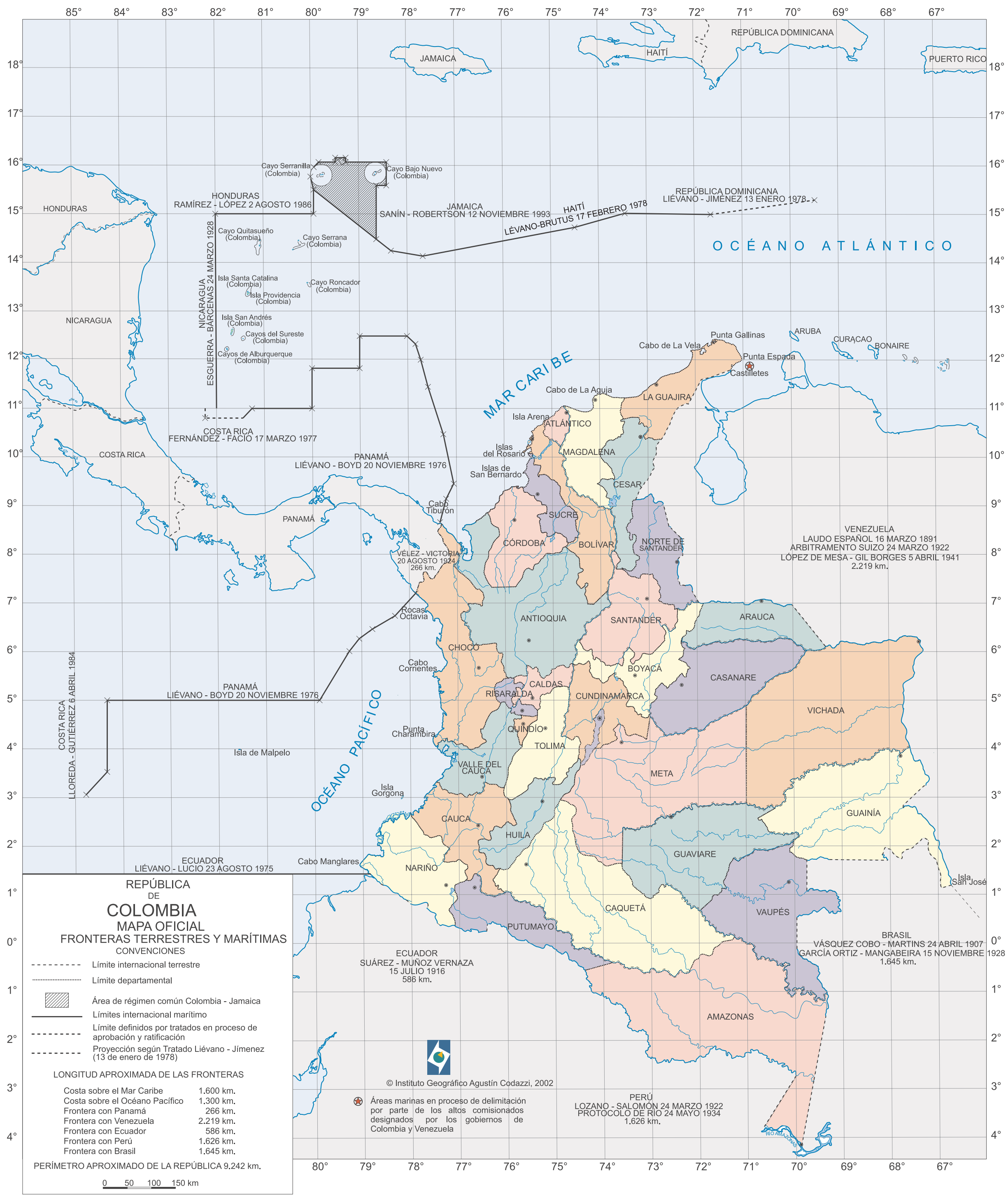

Figure 1. *Official map of terrestrial and maritime frontiers of Colombia (IGAC, 2002).*

Sedimentary Basins of Colombia:

Geological Framework

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From Paleozoic to Late Cenozoic, the basins of Colombia have undergone changes in direction and shape due to different events of rifting and oblique collisions followed by transpression and transtensional tectonics deformation. As a consequence the tectonic evolution of most, if not all, Colombian basins should be considered as poly-history. From a structural/stratigraphic perspective, our knowledge varies greatly from basin to basin. This complicates comparison, especially where an author has emphasized only one aspect of the basin evolution. The northwestern corner of South America, where Colombia is located, has experienced different geologic events that controlled the distribution, genesis, basin fill and bounding structures of the sedimentary basins. In this chapter, the chronology of the main geologic phenomena that occurred in the country are sketched, emphasizing those that generated sedimentary deposits that, nowadays, constitute source rocks, reservoir rocks, sealing units and overburden sequences and finally hydrocarbon traps. In order to describe these events it is necessary to point out that Colombia can be divided in at least three main tectonic domains: 1) The Eastern region limited on the west by the foothills of the Eastern Cordillera (figure 2). It consists of a Paleozoic and Precambrian basement with a Paleozoic-Cenozoic sedimentary cover that has undergone mild deformation; 2) The Central region comprises the Eastern Cordillera, Sierra Nevada de Santa Marta, the Magdalena River valley and the Central Cordillera extending as far as the Romeral fault system to the west (Figure 2) (San Jerónimo and Cauca-Almaguer faults of the Ingeominas Map, 2006). A sedimentary-metamorphic cover rests on a Grenvillian basement believed to be accreted to the South American border during Paleozoic time; 3) The Western region located, at the west of the Romeral fault system (Figure 2), composed of Mesozoic-Cenozoic oceanic terranes accreted to the Continental margin during Late Cretaceous, Paleogene and Neogene.

Lower Paleozoic marine and coastal siliciclastic and carbonate sediments, are distributed throughout the Eastern region (Llanos Basin) and extend into the Central region (Upper Magdalena Valley. Mojica et al., 1988; Trumpy, 1943). These deposits are very fossiliferous which range from Middle Cambrian to Llanvirnian in age. Trilobites, brachiopods, and graptolites in gray to black shales are reported from outcrops in the Upper Magdalena Valley and in many wells drilled in the Llanos basin. In some places, the thermal maturity of these Lower Paleozoic sequences indicates appropriate conditions for hydrocarbon generation.

Dated Lower Paleozoic intrusives outcrop along the Eastern Cordillera and Upper Magdalena basins of the Central region (Etayo-Serna et al., 1983; Forero-Suarez, 1990, Maya, 1992). These intrusives crosscut a low grade metamorphic sequence

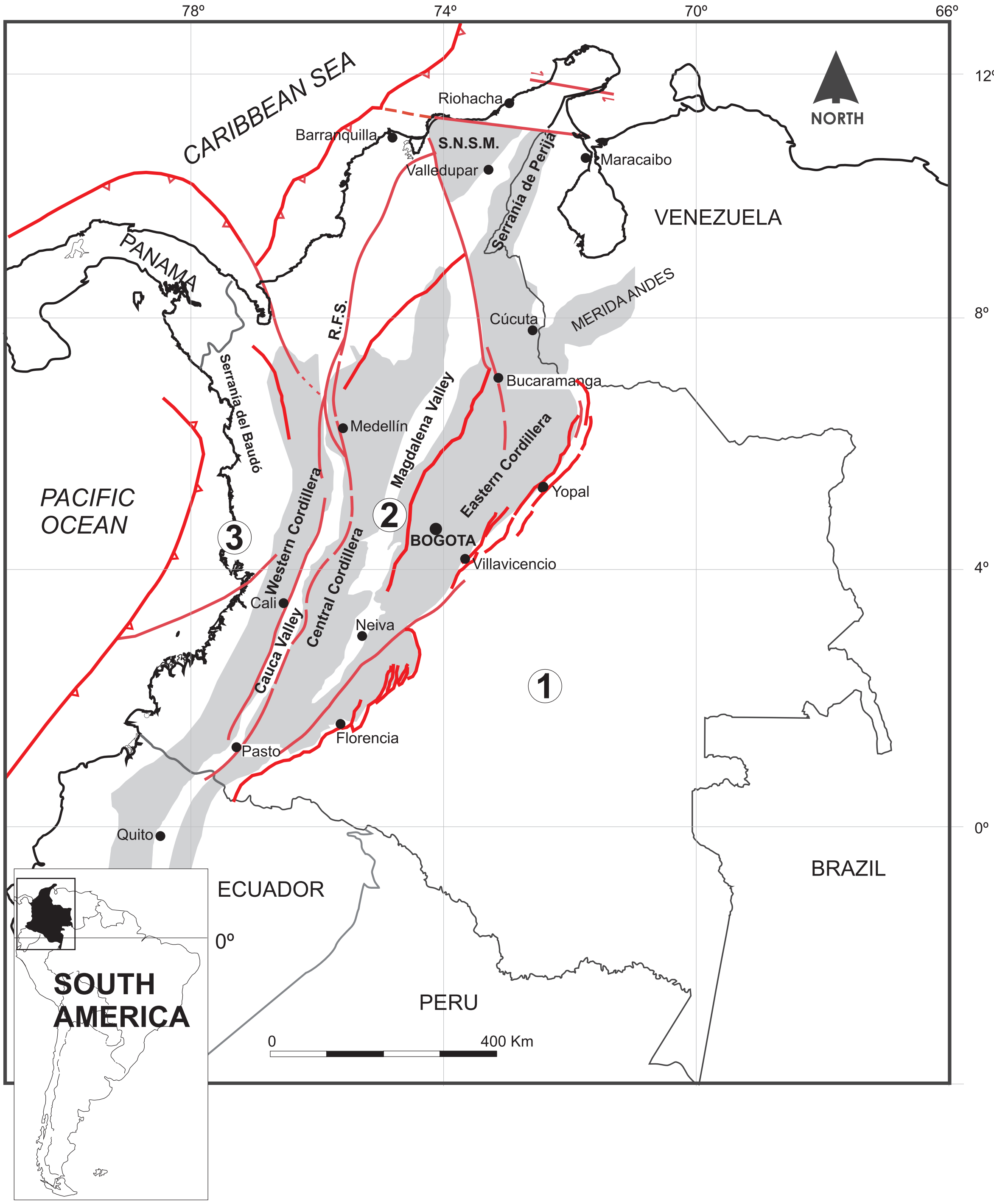

Figure 2. *Map of Colombia with its main tectonic domains. 1) Eastern Region; 2) Central Region; 3) Western Region (explanation in the text). In red: regional faults (see the figure 3 for nomenclature). Gray and shadow areas: Main mountain ranges. R.F.S. Romeral fault system; S.N.S.M. Sierra Nevada de Santa Marta. Deep marine and Los cayos basins are not included.*

and are overlain by Upper Paleozoic sedimentary rocks. Folding, metamorphism and granitic intrusions are probably the result of eastward directed subduction. This regional tectonic event is known as the Caparonensis Orogeny (Restrepo-Pace, 1995; Barrero and Sanchez, 2000; Aleman and Ramos, 2000). The sedimentary sequences in this area consist of marine black shales and continental red-beds of Devonian age. In some places, this continental Devonian is followed by an Upper Carboniferous (Pensylvanian) consisting of limestones, conglomerates, sandstones and graphitic shales with abundant marine fauna. Permian rocks are absent in the southern portion of the Central region. However, farther to the north in the Santander Massif, Serranía de Perijá and Sierra Nevada de Santa Marta, fossiliferous limestones of Lower Permian age have been reported. Folding and granitic intrusions related to shear zones might represent oblique collision and accretion of Upper Paleozoic rocks during formation of the Pangea supercontinent.

Development of most of the Colombian sedimentary basins begins in the Late Triassic (Rolón et al., 2001; Barrero, 2004) during the break-up of Pangea. Early Jurassic to Lower Cretaceous sediments were deposited in a northwest-southeast-northeast trending highly irregular rift system now underlying the Upper Cretaceous to Neogene sedimentary cover (Etayo et al., 1976; Fabre, 1983; Barrero, 2000; Rolón et al., 2001). The post-rift phase of the system is characterized by the formation of a widespread sag due to the thermal subsidence that together with a global eustatic sea level changes during Middle Albian and Turonian times give origin to organic-matter-rich sediments of the Simiti-Tablazo, Tetúan and La Luna source rocks responsible for generating the most of the hydrocarbon found in Colombia.

The Late Cretaceous-Paleogene exhumation of the Central and Eastern cordilleras was linked to the oblique accretion of oceanic rocks (e.g. Western Cordillera basement); as a result a transition from marine, nearshore to continental sedimentary deposits took place. Growth unconformities and fluvial siliciclastic sequences on top of them characterize the Paleogene and Neogene sedimentary fill. These fluvial deposits contain most of the hydrocarbon reserves of Colombia. The Neogene period is characterized by intense volcanic activity in the western edge of the Central Region (Central Cordillera), linked to a collisional event. As a result, the fluvial deposits of the intermontane basins east and west of the Romeral fault system are rich in volcano-clastics (e.g. La Paila, Combia, Honda and Mesa formations). These thick molassic deposits represent the overburden sequences to most of the Petroleum systems of the Colombian basins.

Initial basin geometry in Colombia was drastically modified by the Campanian and Miocene collisional events. The Campanian-Maastrichtian collision of the oceanic rocks to the west gave rise to development of the Colombian foreland-basin system (Barrero, 2004; Gómez et al., 2005). By Early Miocene, a second major transpressional event produced by collision of the Central America Island Arc, break-apart the widespread foreland basin system given origin to a number of broken-foreland basins (intermontane). This final configuration is what is portrait in the sedimentary basins map of Colombia (figure 4).

The Western Region, located west of the Romeral fault system, is composed of mafic and ultramafic rocks, deep-water siliceous shales, turbidites and minor carbonates, in stratigraphic relationship poorly know so far. The tectonic complexity of this region has lead to some authors to use the term complex for units composed of volcanic sedimentary rocks (Maya and Gonzalez, 1995; Moreno-Sanchez and Pardo-Trujillo, 2003). Indeed, some of these complexes are collage of sedimentary/tectonic units highly deformed during oblique collisional events.

The igneous rocks of these complexes consist of Cretaceous basalts of oceanic crust, plateau (Nivia, 1989) and island arc origin incorporated in a west-verging thrust system with right-lateral strike slip component. The basaltic units are intruded by plagiogranites, gabbros, ultramafic rocks and cuarzodiorite stocks (Barrero, 1979; Nivia, 1989). These complexes are covered by Paleogene-Neogene volcanics and mollasic deposits. By Campanian-Maastrichtian time sequence of turbiditic sandstones, siliceous mudstone, calcareous sandstones and black and green shales rich in organic matter is know as the Nogales Formation (Nelson, 1957; Pardo et al., 1993). The Nogales Formation is believed to be the source rock for the oil seep present in the Patía sub-basin (Barrero-Lozano et al, 2006; Rangel et al., 2002) (Figure 4). The entire Western Region is considered to be composed of a still unknown number of allocthonous terranes by most of the geoscientists that had worked in that part of Colombia (e.g. Toussaint, 1996). The general agreement is that the Western Region is part of the Caribbean plate that moves during Late Cretaceous from a Pacific Ocean location to its present position. The precise dynamics and kinematics of this paradigm are still poorly understood and probably will remain so far for a long time.

An important conclusion of the assumed displacement and diachronous oblique collision of the Western Region against the Continental margin of Western Colombia is the need for new kinematic models to explain deformation of the Central and Eastern Regions. As to day, the most plausible kinematic model to explain deformation of the northern Andes is one of dextral transpresion/ transtension system as postulated by Montes, Hatcher and Restrepo-Pace (2005).

Review of Nomenclature and Boundaries of Colombian Basins

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2.1 Brief Historical Overview

Petroleum production in the country began in 1921 with the granting of the Barco and De Mares concessions, which included the jungle regions of Catatumbo at the Venezuelan frontier and those of Opón - Carare, in the Middle-Magdalena.

ECOPETROL was authorized by the government since 1969 to work lands other than those of the former De Mares Concession (Barco and Infantas or Catatumbo and VMM). In 1974, Colombia began using the Association Contract system, which became an important tool in hydrocarbon exploration, through the addition of private capital (domestic and foreign), in association with ECOPETROL.

In 1985, Govea and Aguilera, ECOPETROL employees, published an article describing 13 sedimentary basins for Colombia. According to the authors, their origin is related to Andean orogeny, and they used the classification of Kingston et al. (1983), as a basis. Three groups were recognized:

- Continental Basins: Eastern Llanos, Putumayo, Mid-Magdalena Valley, Upper Magdalena Valley, Catatumbo, Cesar – Ranchería, Sabana de Bogotá, Amazon and Los Cayos
- Continental borderland Basins: Lower Magdalena Valley and Guajira.
- Oceanic Basins: Chocó - Pacific and Cauca - Patía.

Subsequent to this proposal, ECOPETROL (2000) presented a map with a subdivision of 18 basins, which was adopted by the ANH (figure 3). Given that, to our knowledge, there is no official document indicating in detail the geological and/or geographical characteristics used to delimit these basins, the technical assistant directorate of the ANH is setting forth a proposal to review the nomenclature and boundaries of the Colombian sedimentary basins presented in this document.

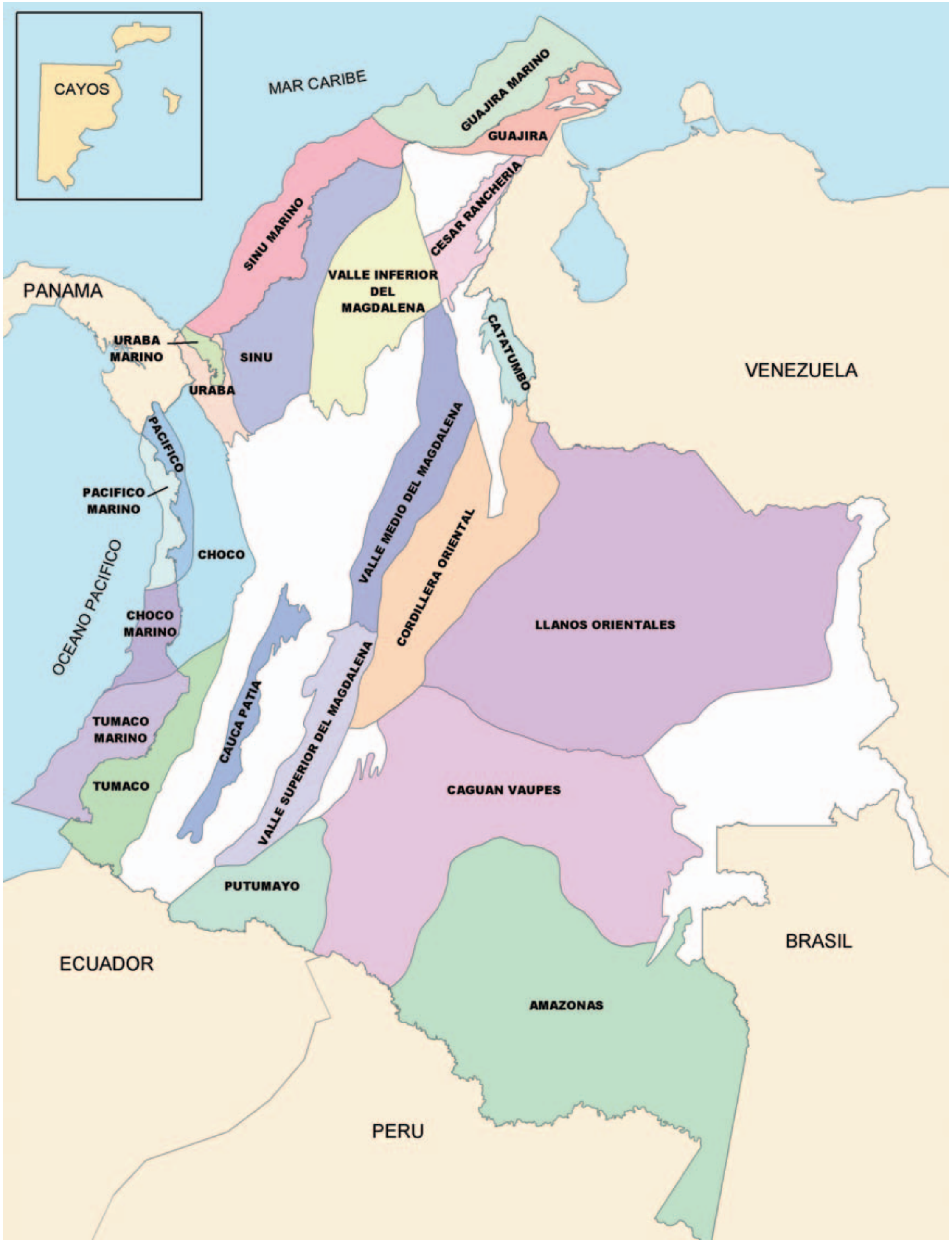


Figure 3. *Classification of sedimentary basins in Colombia (ECOPETROL, 2000) and adopted in the ANH land map (http://www.anh.gov.co/html/i_portals/index.phz).*

2.2 Colombian Basin Nomenclature and Boundaries

The nomenclature and boundaries of the Colombian Sedimentary basins as they appear in the ANH land map need some clarification based on geological and/or planning and operation criteria for exploration activities in the petroleum industry.

It is important to mention that some of these regions do not strictly meet the definition of a sedimentary basin, given that they correspond to areas which have undergone different geological events over time. They could be best defined as Geologic Provinces which, accordingly with the USGS (2000): "each geologic province is an area having characteristic dimensions of perhaps hundreds to thousands of kilometers encompassing a natural geologic entity (for example, sedimentary basin, thrust belt, delta) or some combination of contiguous geologic entities" and their limits are drawn along natural geologic boundaries or, in some cases, at an arbitrary water deep in the oceans. Nevertheless, the term sedimentary basin is conserved here because it is deep-rooted in the geological literature of Colombia. The new proposal divides the Colombian territory in 23 sedimentary basins (figure 4 and 5):

1. Amagá
2. Caguán-Putumayo
3. Catatumbo
4. Cauca-Patía
5. Cesar-Ranchería
6. Chocó
7. Chocó Offshore
8. Colombia
9. Colombian Deep Pacific
10. Eastern Cordillera
11. Eastern Llanos
12. Guajira
13. Guajira Offshore
14. Los Cayos
15. Lower Magdalena Valley
16. Middle Magdalena Valley
17. Sinú-San Jacinto
18. Sinú Offshore
19. Tumaco
20. Tumaco Offshore
21. Upper Magdalena Valley
22. Urabá
23. Vaupés-Amazonas

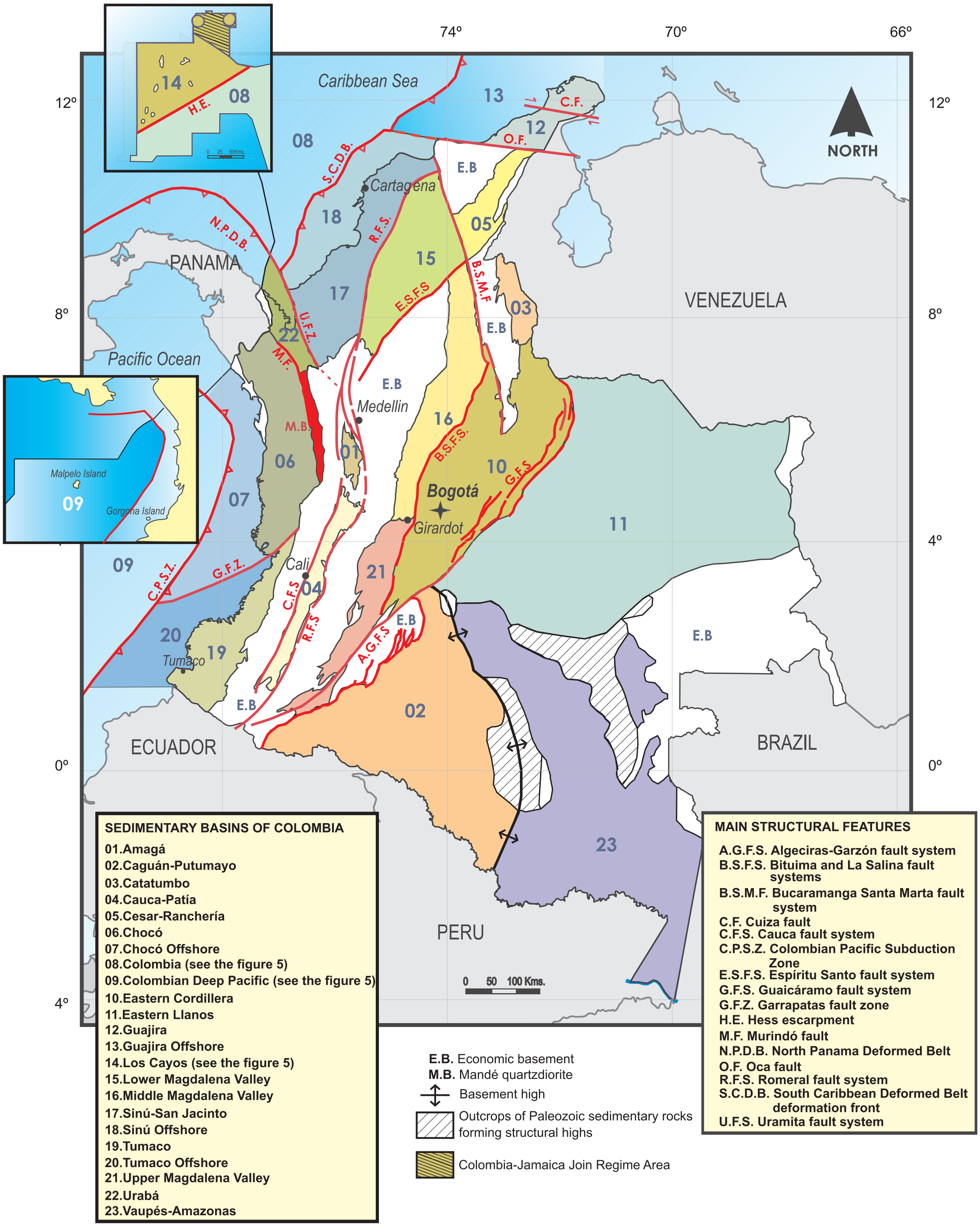


Figure 4. *Proposed basin map of Colombia for ANH 2007.*

2.3 Proposed Modifications to the Sedimentary Basin Map of Colombia

It is proposed to include the Amagá Basin in the Antioquia region. Despite its low prospectiveness for conventional hydrocarbon exploration, the sedimentary rocks in this region are rich in organic material and coal, which must be evaluated for hydrocarbon extraction by non-conventional methods. The northern limit of the Guajira Offshore and Sinú Offshore basins were extended to the South Caribbean Deformed Belt deformation front (figure 4).

The Basin called "Pacífico" in the basin map of the ANH was included among the "economic basement", as it corresponds for the most part to basic igneous rocks of the Baudó Mountain Range. Thus, the new onshore basins of the Pacific area would be divided into the Chocó basin to the north and the Tumaco basin to the south, separated by the Garrapatas fault zone (figure 4). Two deep marine basins are included in this proposal: the Colombian Basin in the Caribbean and the Colombian Deep Pacific Basin in the Pacific Ocean which are mainly limited by international maritime boundaries (figure 5).

In the region that includes the Putumayo, Caguán-Vaupés and Amazon basins (figure 3), it is proposed that it be separated into two prospective areas (figure 4): 1) The Vaupés-Amazonas basin, which corresponds to an elongated depression extending from the east margin of the Eastern Cordillera, down southeast to the Amazon River. The eastern and western boundaries of this basin correspond to structural high grounds composed of Paleozoic rocks (e.g. Chiribiquete mountain range to the W and La Trampa mountain range, Diamaco and Circasia hills and Carurú plateau to the E; figure 4). According to its morphology and gravimetric information, this basin corresponds to a graben which could be a prolongation to the north of the Solimoes Basin. 2) The Caguán-Putumayo Basin: it is proposed to extend the former Putumayo Basin to the western edge of Chiribiquete structural high ground (figures 3 and 4). The Paleozoic rocks of the subsurface could present prospectiveness, considering that, to the south, in the Peruvian Basin of Marañón, important hydrocarbon reserves have been discovered in rocks of this age.

2.4 Proposed Boundaries

The objective of this chapter is to introduce the user in a new proposal about the boundaries of the sedimentary basin of Colombia, as they are described by geoscientist of the ANH (figures 4 and 5). It should be taken in consideration the great difficulty in defining boundaries for basins with a poly-historic development, as it is the case for most of the Colombian sedimentary basin.

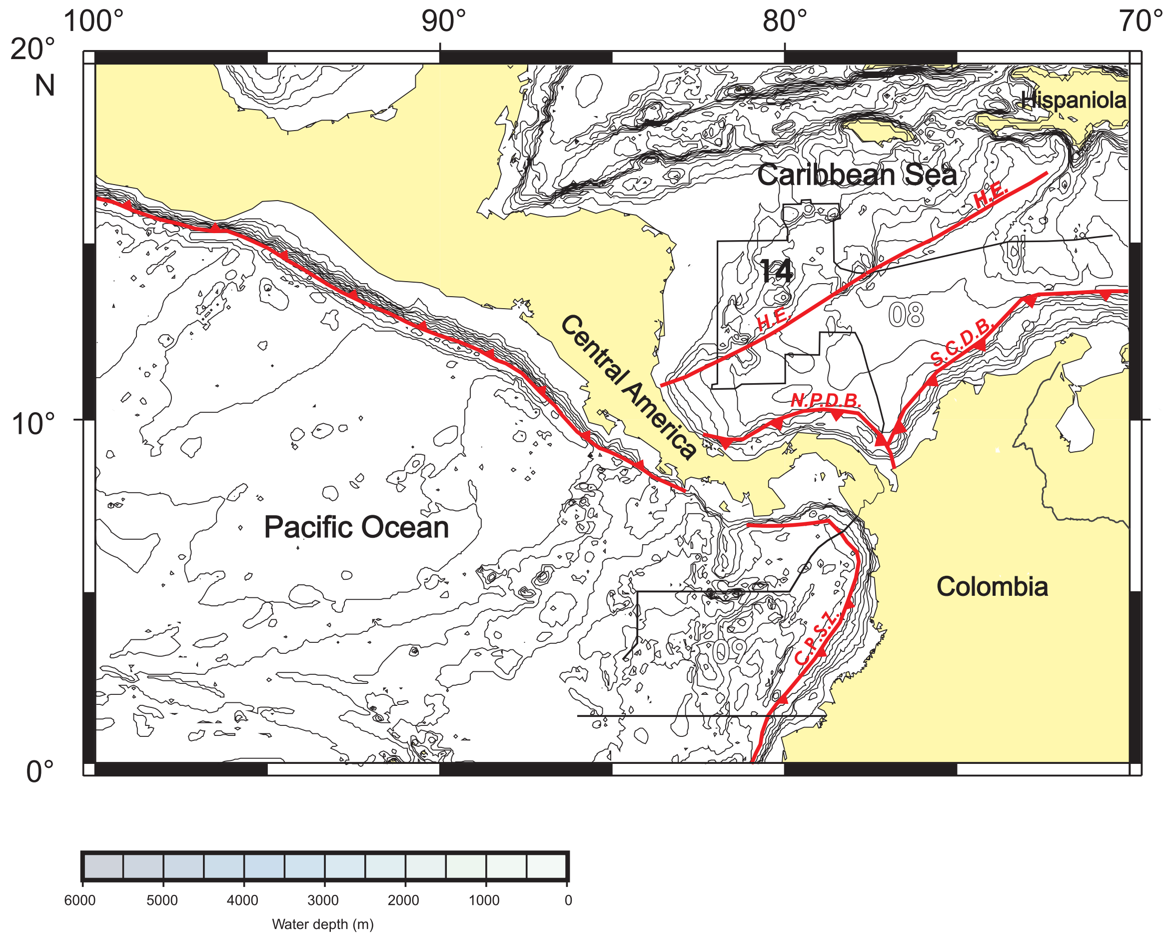
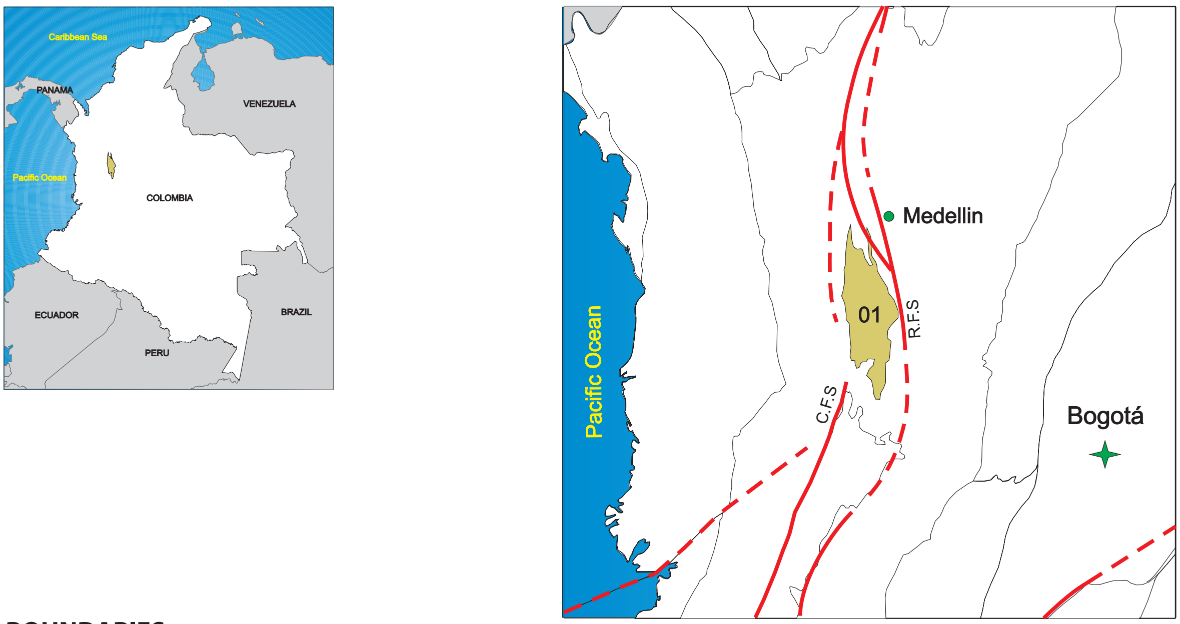


Figure 5. *Bathymetric map of the eastern Pacific Ocean and the Caribbean Sea and location of the Los Cayos (14), Colombia (08) and Colombian Deep Pacific (09) basins. Limits are mainly based on the official map of the Colombian maritime boundaries (IGAC, 2002). H.E. Hess Escarpment; C.P.S.Z. Colombian Pacific Subduction Zone; S.C.D.B. South Caribbean Deformed Belt deformation front; N.P.D.B. North Panama Deformed Belt deformation front. Map modified from Niitsuma et al. (2006).*

Amagá Basin

Amagá Basin

The Amagá Basin is a collision-related basin, formed to the west of the Romeral fault system. It covers an area located in the southwest of the Departamento de Antioquia and the northern edge of Departamento de Caldas (figures 1 and 4). The west and east limits of this basin are the Cretaceous igneous and sedimentary rocks of the Central and Western cordilleras and partially regional faults (figure 6). It consists of fluvial deposits with important coal layers buried by Neogene volcanoclastics, tuff and lava flows. This small basin could be an important exploration target for coal-bed methane.



BOUNDARIES

East: Cretaceous igneous-sedimentary rocks (Central Cordillera)

West: Cretaceous volcanic and sedimentary rocks (Western Cordillera)

R.F.S. Romeral fault system

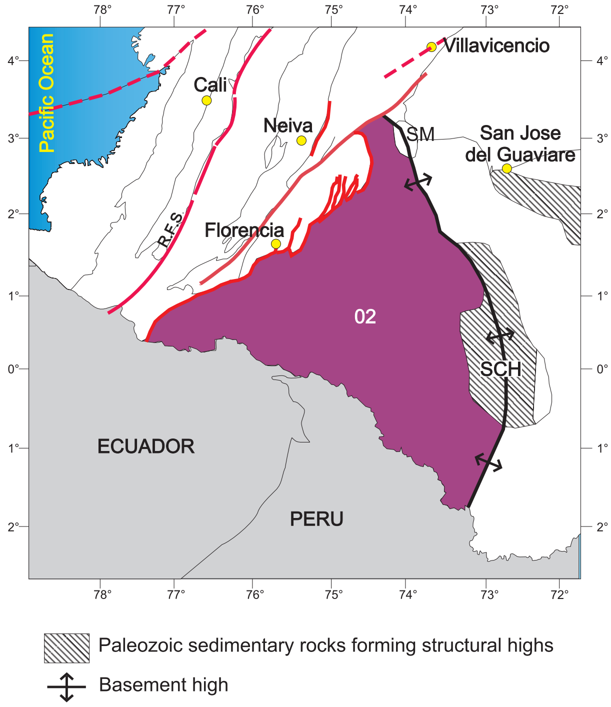
C.F.S. Cauca fault system

Figure 6. *Amagá Basin (01), location and boundaries.*

Caguán - Putumayo Basin

Caguán - Putumayo Basin

This new-named basin is the northernmost extension of the Oriente-Marañon basin. In this document it is proposed to extend the limits of the Putumayo basin to include the area of the Caguán sedimentary section, taken in consideration the presence of a prospective Paleozoic section as such found in Perú. The limits of this basin are: the Eastern Cordillera foothills thrust system to the northwest; the Macarena structural high to the northeast; the Ecuadorian and Peruvian international border to the south and a structural high to the east, which includes the Serranía de Chiribiquete (figure 7). General information: Higley, 2001; Mathalone and Montoya, 1995.



BOUNDARIES

Northwest: Eastern Cordillera foothills fault system

East: Structural high, including the Serranía de Chiribiquete (SCH)

South: Ecuadorian-Peruvian International border

Northeast: Sierra de la Macarena (SM)

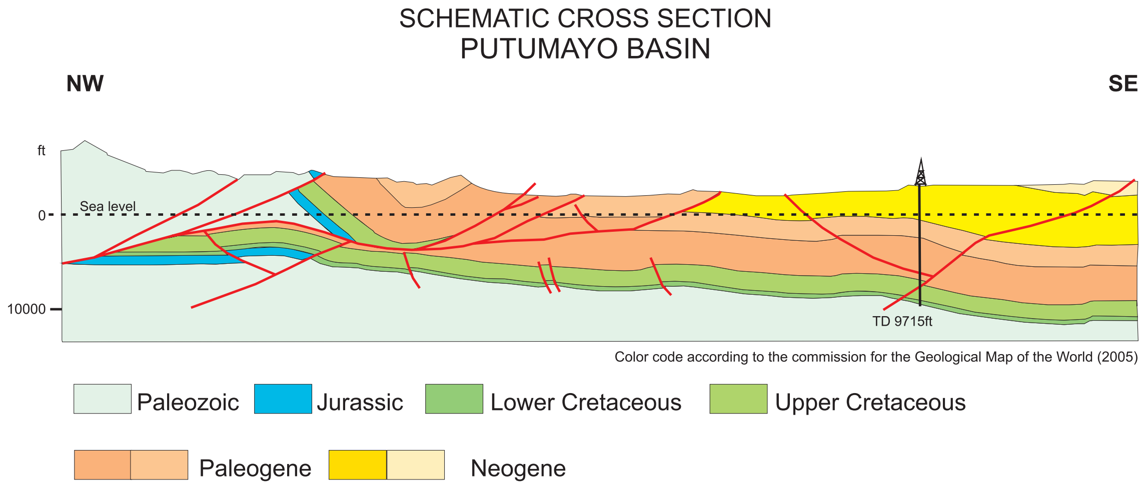
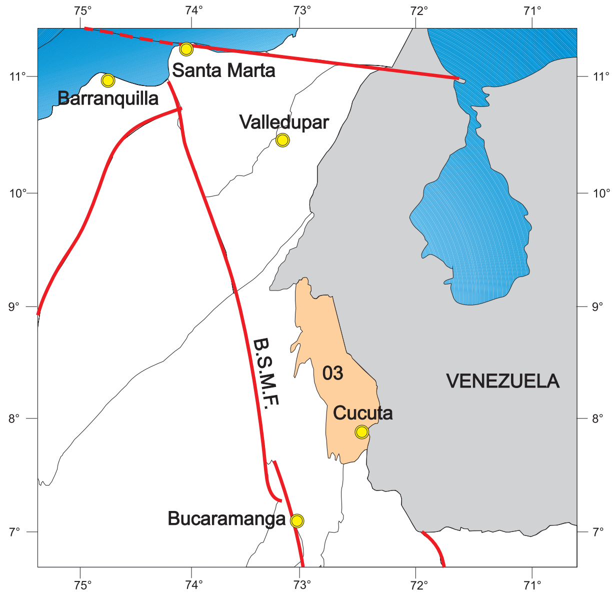


Figure 7. *Caguán - Putumayo Basin (02), location and boundaries.*

Catatumbo Basin

Catatumbo Basin

The Catatumbo Basin is the Colombian portion of the Maracaibo Basin, a petroleum supergiant basin that accounts for about two percent (2%) of the hydrocarbon reserves of the world. Its north and east limits are the geographic border with Venezuela; to the south the limit is with outcropping Cretaceous rocks of the Eastern Cordillera and, to the west the igneous and metamorphic rocks of the Santander massif (figure 8). General information in: Mann et al., 2006; Talukdar and Marcano, 1994; Yurewicks et al., 1998, Alfonso and Mondragón, 2000.



B.S.M.F. Bucaramanga-Santa Marta Fault System

BOUNDARIES

North: Geographic Border with Venezuela

South: Eastern Cordillera Cretaceous rocks

West: Santader Massif igneous and metamorphics

East: Geographic Border with Venezuela

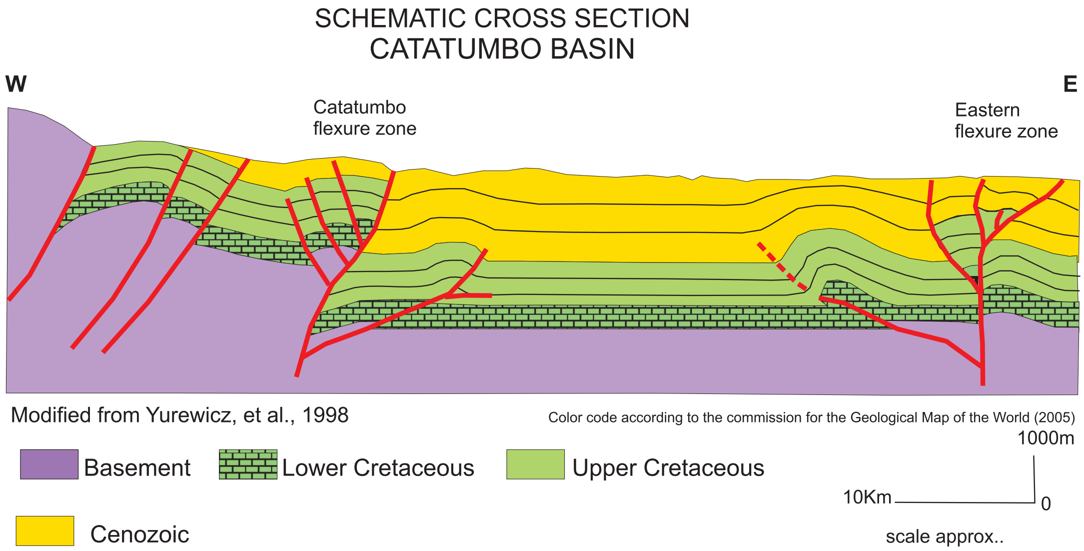
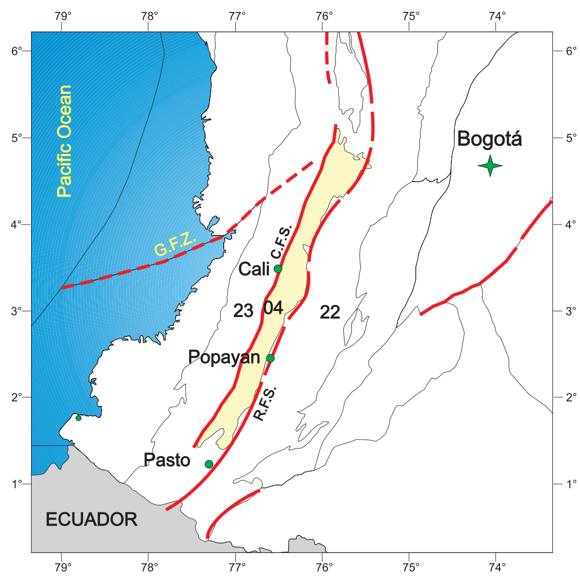


Figure 8. *Catatumbo Basin (03), location and boundaries.*

Cauca-Patía Basin

Cauca-Patía Basin

This Cenozoic collision-related basin is bounded to the north and south by basic igneous rocks of Late Cretaceous age. Its eastern and western limits are regional tectonic features (figures 4 and 9). The eastern limit is partially defined by the Romeral fault system, which separate continental crust to the east from oceanic crust to the west. General information in: Barrero et al., 2006; Barrero, 1979; Barrero and Laverde, 1998; Aleman and Ramos, 2000; Rangel et al., 2002; Moreno-Sánchez and Pardo-Trujillo, 2003.



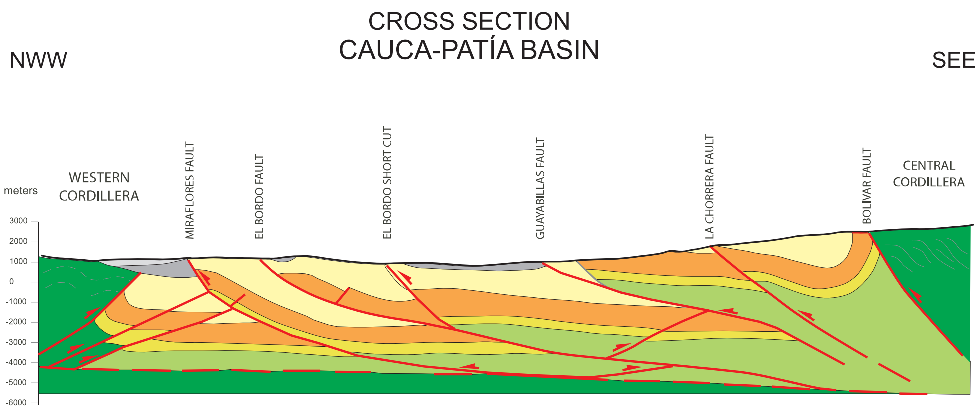
G.F.Z. Garrapatas fault system

BOUNDARIES

West: Cauca fault system (C.F.S.), Western Cordillera volcanic and sedimentary rocks (23)

East: Romeral fault system (R.F.S.), Central Cordilera (22)

North and South: Cretaceous basic igneous rocks

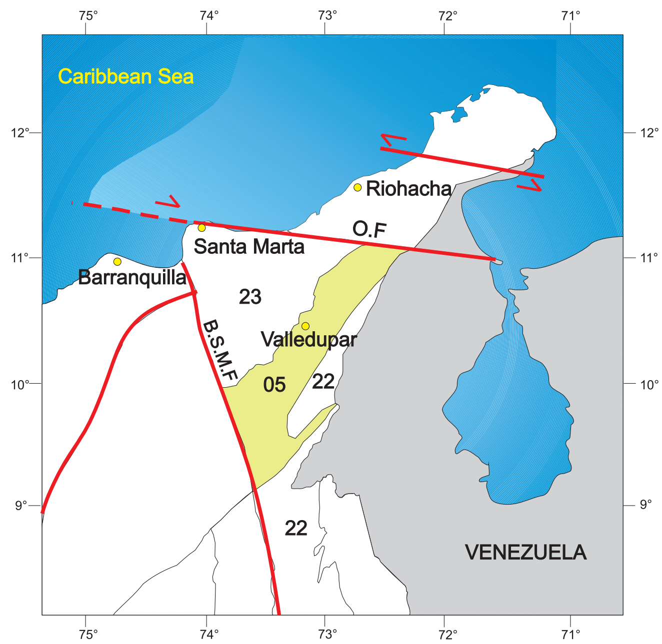


Taken from Barrero-Lozano D., et al. 2006

Figure 9. *Cauca-Patía Basin (04), location and boundaries.*

Cesar-Ranchería Basin

This intermontane (broken-foreland) basin is bounded to the northwest by the Pre-Cretaceous rocks of the Sierra Nevada de Santa Marta. The northeast limit is the sharp trace of the Oca fault; to the east-southeast the limit is the pre-Cretaceous rocks of the Serranía de Perijá and the Colombian-Venezuelan boundary, and to the southwest the trace of the Bucaramanga fault (figure 10). This basin has a general orientation N30°E and, the Verdesia high divides it in the southern Cesar and the northern Ranchería sub-basins.



BOUNDARIES

SW: Bucaramanga-Santa Marta Fault (B.S.M.F)

E-SE: Pre-Cretaceous rocks of the Serranía de Perijá (22); Colombian-Venezuelan boundary.

NE: Oca Fault (O.F.)

NW: Pre-Cretaceous rocks of the Sierra Nevada de Santa Marta (23)

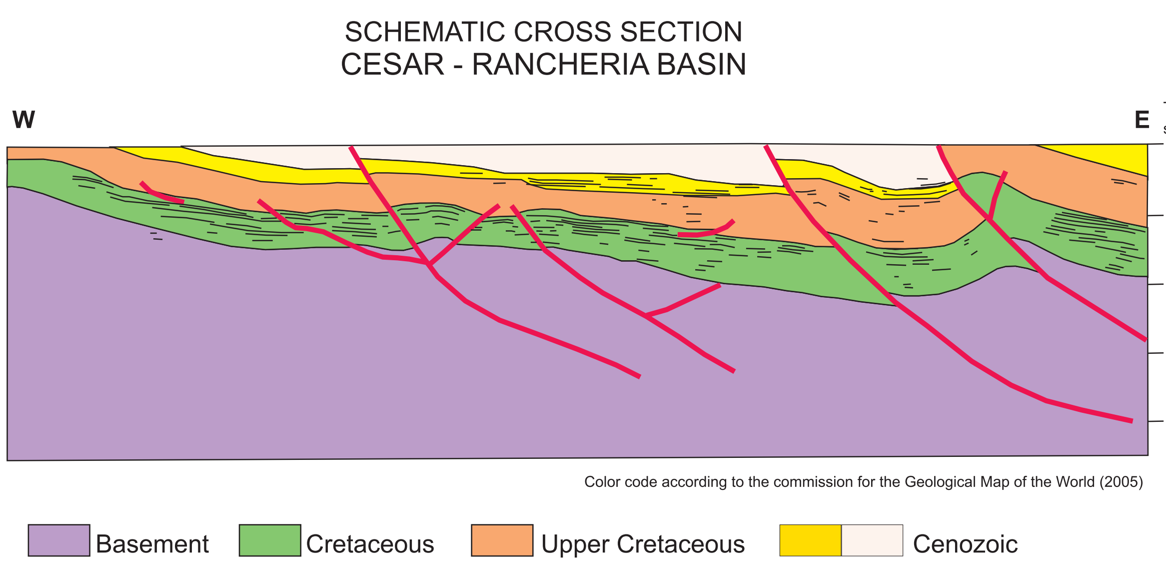
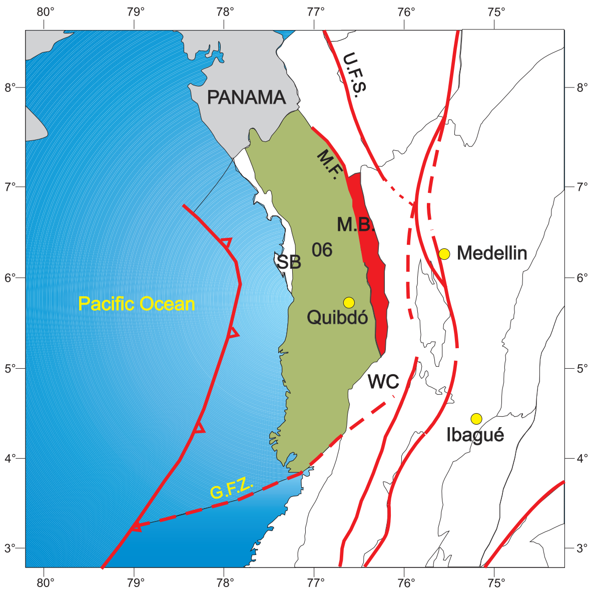


Figure 10. *Cesar-Ranchería Basin (05), location and boundaries.*

Chocó Basin

Chocó Basin

This basin has been interpreted as the product of extension in a forearc setting. The north-northwest limit of the basin is the geographic boundaries with Panamá; to the northwest the basin sediments lap on the basaltic complex of the Serranía de Baudó; the southwest limit is the present Pacific coastal line; the east limit is the quartzdioritic Mandé batholith the Cretaceous rocks of the Western Cordillera and partially, the Murindó fault. The Garrapatas fault zone, a NNE trending shear zone, marks the south limit of the basin (figure 11). This sedimentary area has been subdivided in two basins for some authors (e.g. Duque-Caro, 1990): the Atrato Basin to the north and the San Juan Basin to the South divided by the Itsmina fault zone. General information: Barrero, 1979; Geotec, 1988; Duque-Caro, 1990; Aleman and Ramos, 2000; IGAC-Ingeominas, 2001.



BOUNDARIES

N-NW: Geographic border of Panamá

South: Garrapatas fault zone (G.F.Z.)

NW: Serranía de Baudó (SB)

SW: Present Pacific coastline

East: Mande quartzdiorite (M.B.), the Cretaceous rocks of the Western Cordillera (WC) and partially the Murindó fault (M.F.)

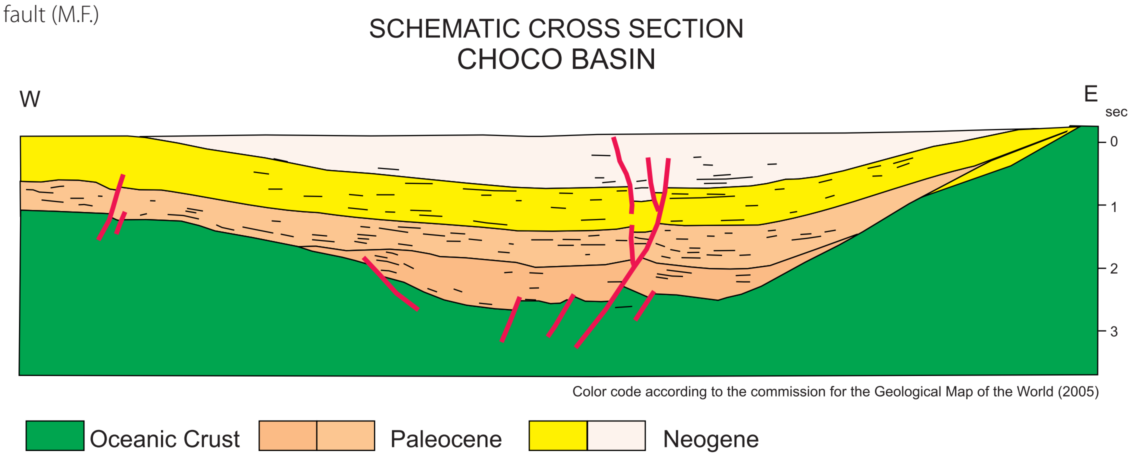
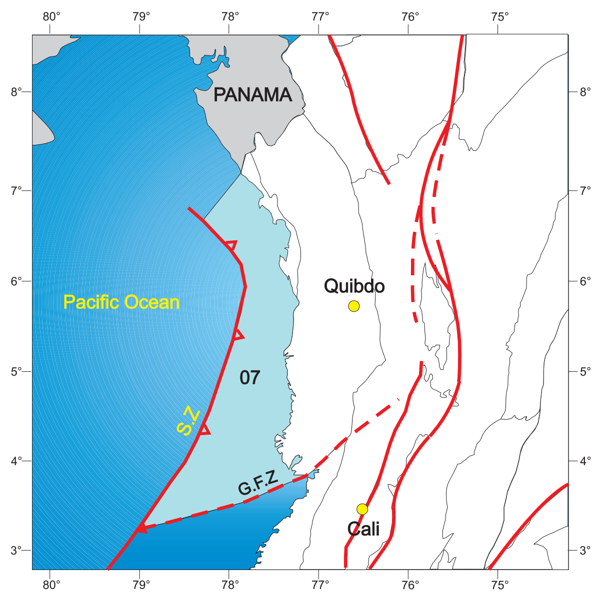


Figure 11. *Chocó Basin (06), location and boundaries.*

Chocó Offshore Basin

Chocó Offshore Basin

The Chocó Offshore Basin is located along the arcuate corner of northwestern Colombia, south of the Panama border, under waters of the Pacific Ocean. This offshore basin extends from the west of the present coastal line as far as the trench of the present subduction zone. To the north the basin limit is the Panama border, and to the south the limit is roughly the trace of the Garrapatas fault system (figure 12). General information: IGAC-Ingeominas, 2001; Ingeominas, 2006; Geotec, 1988.



BOUNDARIES

NNE: Geographic border of Panama

South: Garrapatas fault zone (G.F.Z.)

West: Trench of the present subduction zone (S.Z.)

East: Present coastal line

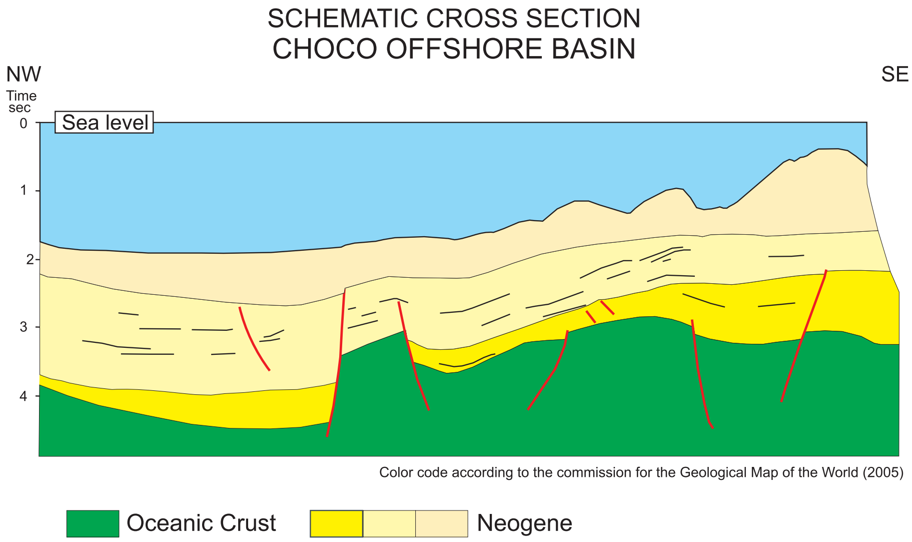


Figure 12. *Chocó offshore Basin (07), location and boundaries.*

Colombia Basin

The Colombian Basin is a deep water basin located in the Caribbean Sea. Its northwestern limit is considered here the Hess Escarpment, a major feature extending from eastern Central America to Hispaniola (Figure 5). The southwestern limit of this basin is the Costa Rica and Panama maritime boundaries, the southeastern limit is located in the South Caribbean Deformed Belt deformation front; the eastern boundary is the maritime Colombian-Venezuelan frontier, and the northern limit is the Jamaica, Haiti and the Dominican republic maritime boundaries (figures 4 and 5). Due to the petroleum geology of this basin is still unknown; it is not mentioned in the next section of this book. General information: Mann, 1999.

Colombian Deep Pacific Basin

This name is proposed here to include the westernmost marine basin of Colombia, which is mainly composed by oceanic volcanic rocks and deep marine sediments. Its northern limit is located in the Colombian-Panama maritime boundaries; the western limit is placed in the Colombian-Costa Rica boundary; to the south it is bounded by the Colombian-Ecuadorian marine boundary. To the east the basin is limited by the Colombian Pacific Subduction Zone (figure 5).

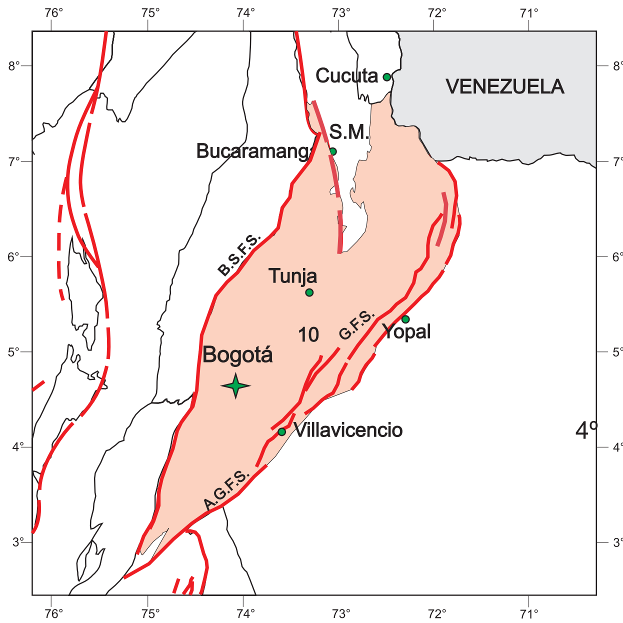
Eastern Cordillera Basin/Fold belt

The Eastern Cordillera basin is composed by rocks formed in an inverted Late Triassic rift system that resulted from the break-up of Pangea (Rolón et al., 2.001) and was filled by Mesozoic marine and Cenozoic continental sediments. By Early Paleogene a dextral transpressional deformation triggered faulting and folding and played a fundamental role in the structural inversion of this basin.

As a consequence of its origin and structural development the present day limits of the basin are very irregular and difficult to describe. In a general way, east and west limits are well developed en-echelon faults that thrust-over the adjacent basins, the eastern limit is known as the frontal thrust system of the Eastern Cordillera; the western limit are the Bituima and La Salina fault systems (Llinas, J.C., 2.001, La Luna Oil, Internal report). The southeast boundary is the Algeciras-Garzón dextral strike-slip fault system, and the northern limit the igneous and

Eastern Cordillera Basin Fold belt

metamorphic rocks of the Santander massif (figure 13). The eastern portion of the basin is the well-known Llanos Foothills. General information: Casero et al., 1997; Montes, et al., 2005; Gómez, et al., 2005; Rolón, et al., 2001; Kammer, 1999; Restrepo-Pace, 1989; Restrepo-Pace, 1999; Dengo and Covey, 1993; Julivert, 1958; Fabre, 1985.



BOUNDARIES

North: Igneous and metamorphic rocks from the Santander massif (S.M.)

South: Algeciras-Garzón fault system (A.G.F.S.)

West: Bituima and La Salina fault systems (B.S.F.S.)

East: frontal thrust system of the Eastern Cordillera

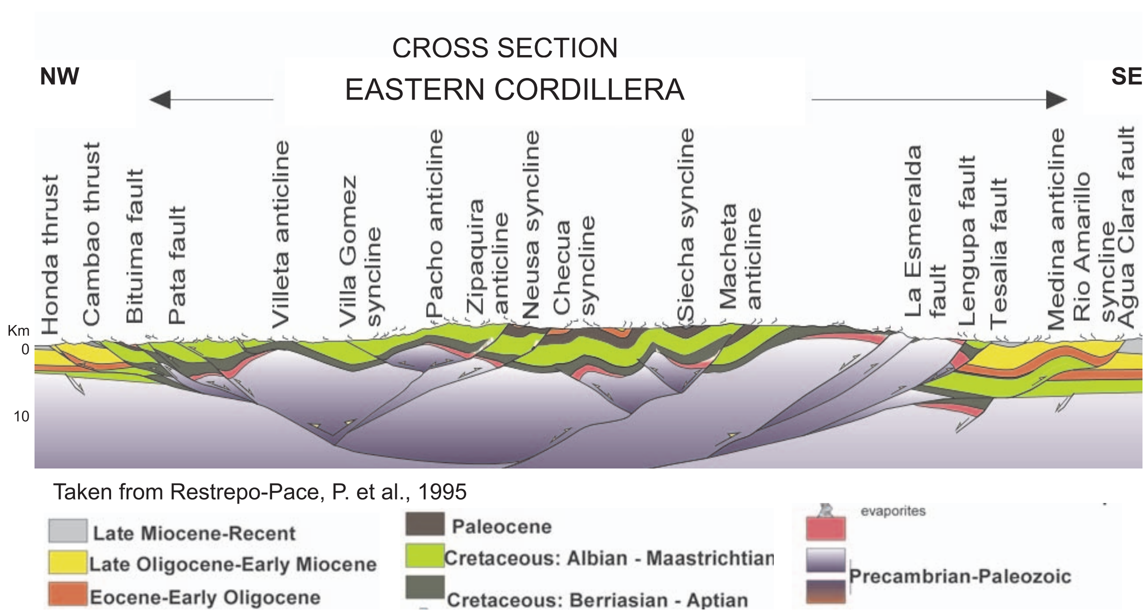


Figure 13. *Eastern Cordillera Basin (10), location and boundaries.*

Eastern Llanos Basin

The Eastern Llanos Basin is the most prolific hydrocarbon basin in continental Colombia. The northern limit of this basin is the Colombian-Venezuelan border; to the south the basin extend as far as the Macarena high, the Vaupés Arch and the Precambrian metamorphic rocks that outcrops to the south of the Guaviare river; the eastern limit is marked by the outcrops of Precambrian plutonic rocks of the Guyana Shield and to the west the basin is limited by the frontal thrust system of the Eastern Cordillera (figure 14). General information: Casero et al.,1997; Gómez et al., 2005; Etayo-Serna et al., 1983; Cooper et al., 1995.

BOUNDARIES

North: Geographic Border Venezuela

South: Serranía de la Macarena (SM), Vaupés Arch (VA), and Precambrian metamorphic rocks (PM)

West: frontal thrust system of the Eastern Cordillera

East: Guyana Shield Precambrian rocks (GS)

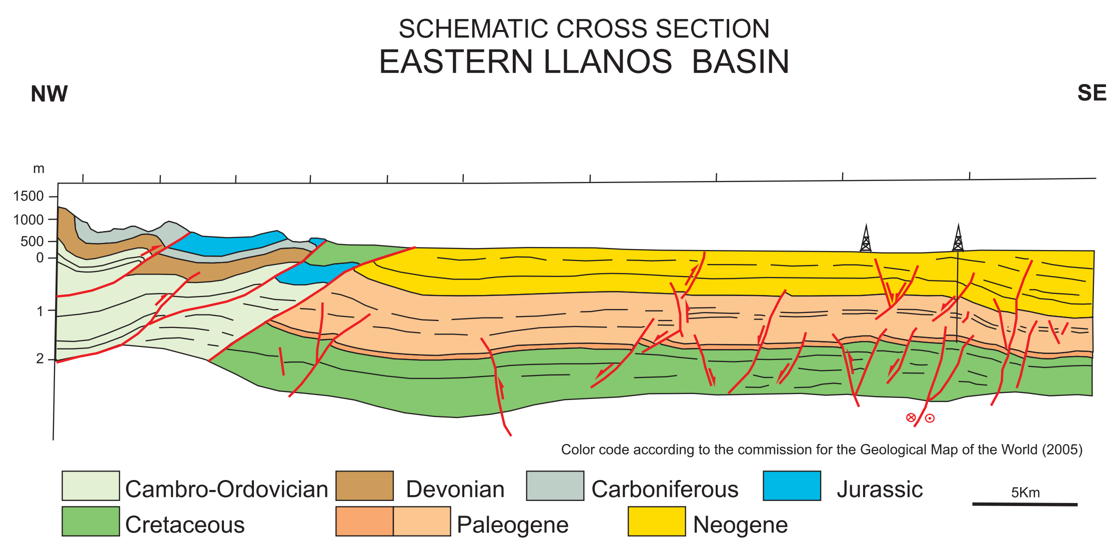
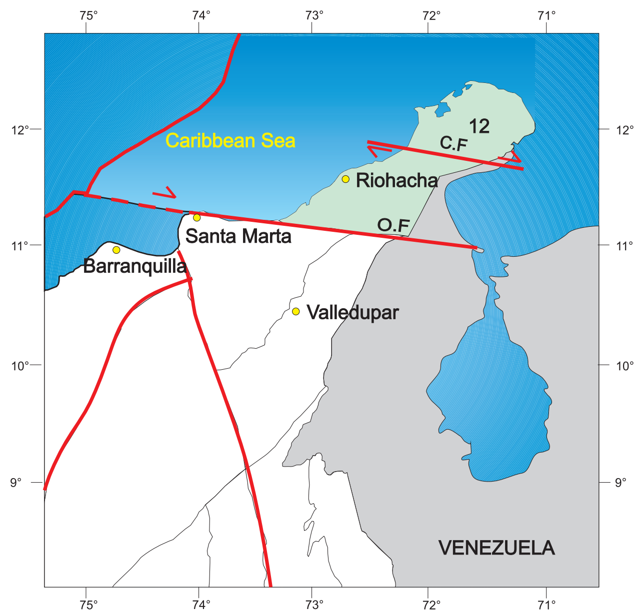


Figure 14. *Eastern Llanos Basin (11), location and boundaries.*

Guajira Basin

The Guajira Basin is located in the northernmost region of Colombia. The north, northwest and northeast limits of the basin are the present Caribbean coastline; the southeast limit is the geographic boundary with Venezuela; the southern limit is the trace of the Oca fault (figure 15). The basin has been divided by the trace of the Cuiza fault into Upper Guajira and Lower Guajira sub-basins. From a kinematic point of view, the Lower Guajira is here considered a geologic feature formed as a consequence of a releasing step-over in a transtensional environment of the Oca-Cuisa fault system. General information: Barrero-Lozano, 2004; Geotec, 1988; Ingeominas, 2006; Mann, 1999.



BOUNDARIES

North and Northwest: Caribbean shoreline

Northeast: Caribbean shoreline

South: Oca Fault (O.F.)

Southeast: Colombia-Venezuela border

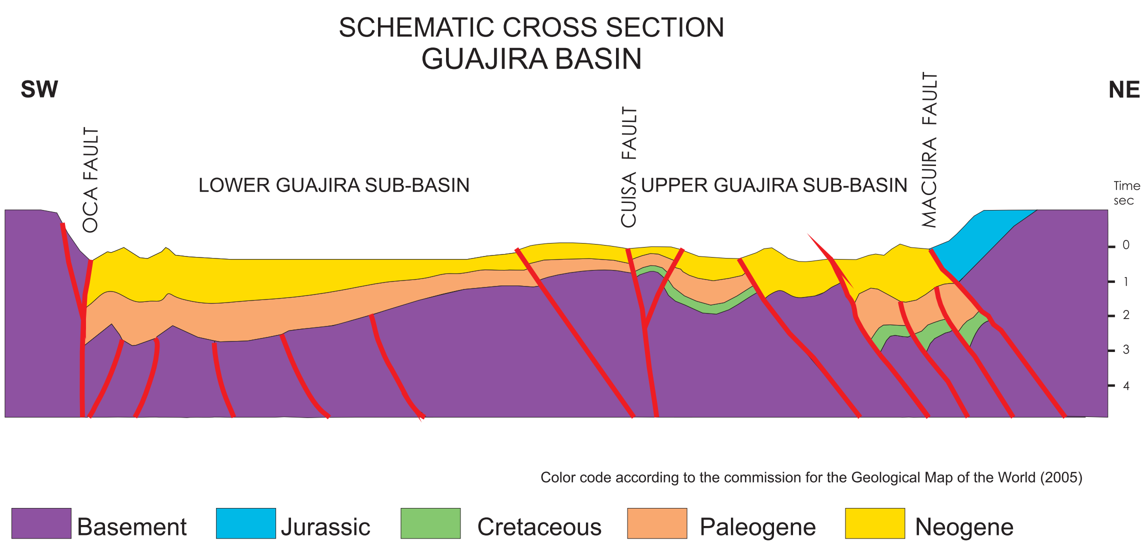
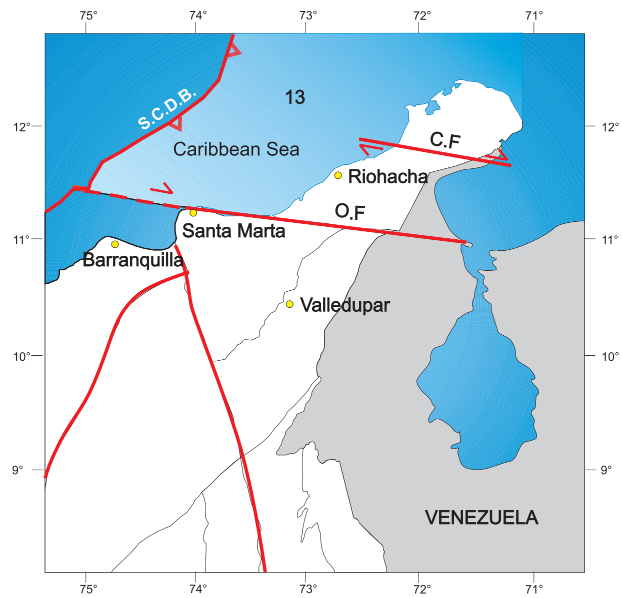


Figure 15. *Guajira Basin (12), location and boundaries.*

Guajira Offshore Basin

The northern-northwestern limit of this basin is the South Caribbean Deformed Belt deformation front originated by the interaction between the South American and the Caribbean Plate; to the east the limit is the geographic line defining the Colombia-Venezuela border; to the southwest the basin goes as far as the offshore trace of the Oca fault and to the Southeast the continental Guajira shoreline (figure 16). General information: Cediel et al., 1998; Geotec, 1988; Ingeominas, 2006; Mann, 1999.



BOUNDARIES

North-Northwest: South Caribbean Deformed Belt deformation front (S.C.D.B.)

Southwest: Oca Fault (O.F.)

Southeast: Continental Guajira shoreline

East: Colombia-Venezuela border

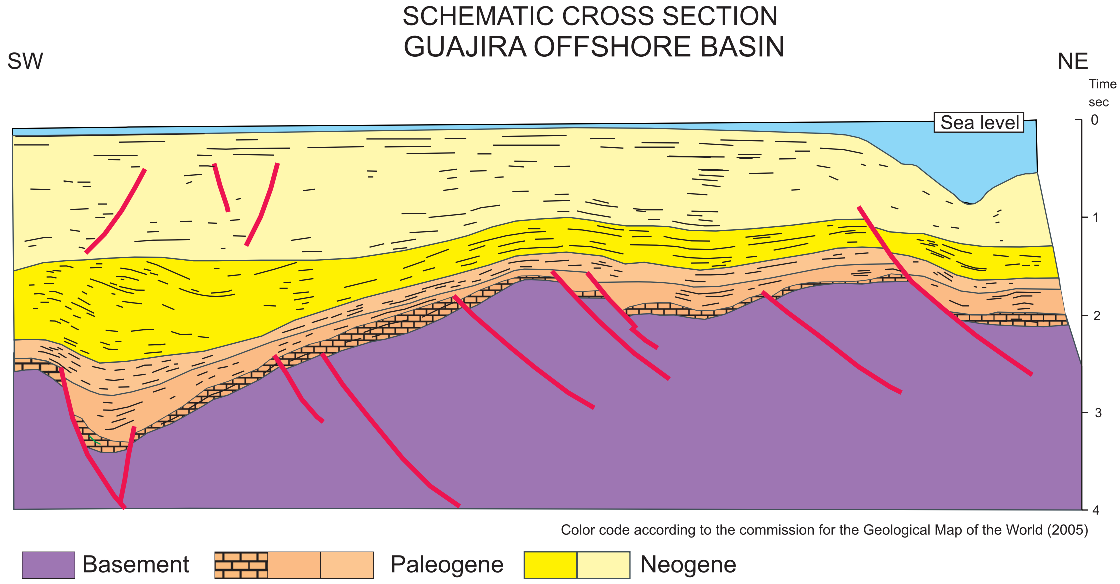
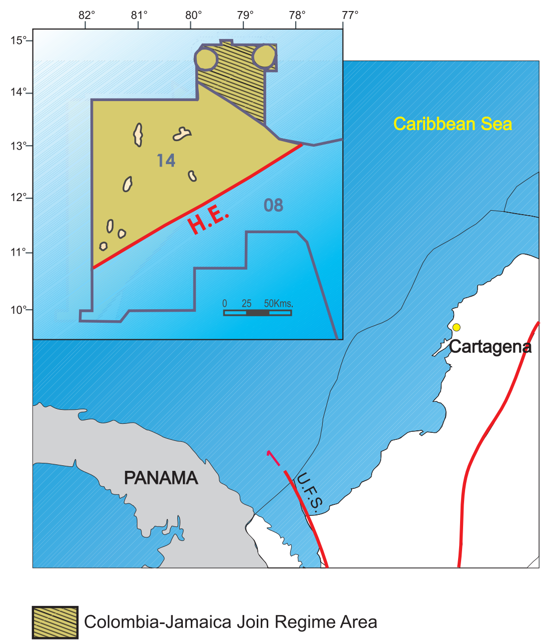


Figure 16. *Guajira offshore Basin (13), location and boundaries.*

Los Cayos Basin

Los Cayos Basin

Los Cayos Basin is an oceanic basin within the Caribbean Sea region. The north and western limits of this basin are the international boundaries (figures 5 and 17); the east southeastern limit is considered here the Hess escarpment (figure 5) which separates the Nicaraguan Rise to the norhwest and the Colombian basin to the Southeast. The basin fill consist of a Paleogene carbonate-siliciclastic sequence followed by Neogene siliciclastics. Basement rocks are Cretaceous siliceous deposits and basalts.



BOUNDARIES

North, East and West: International boundaries

South-Southeast: Hess Escarpment (H.E.)

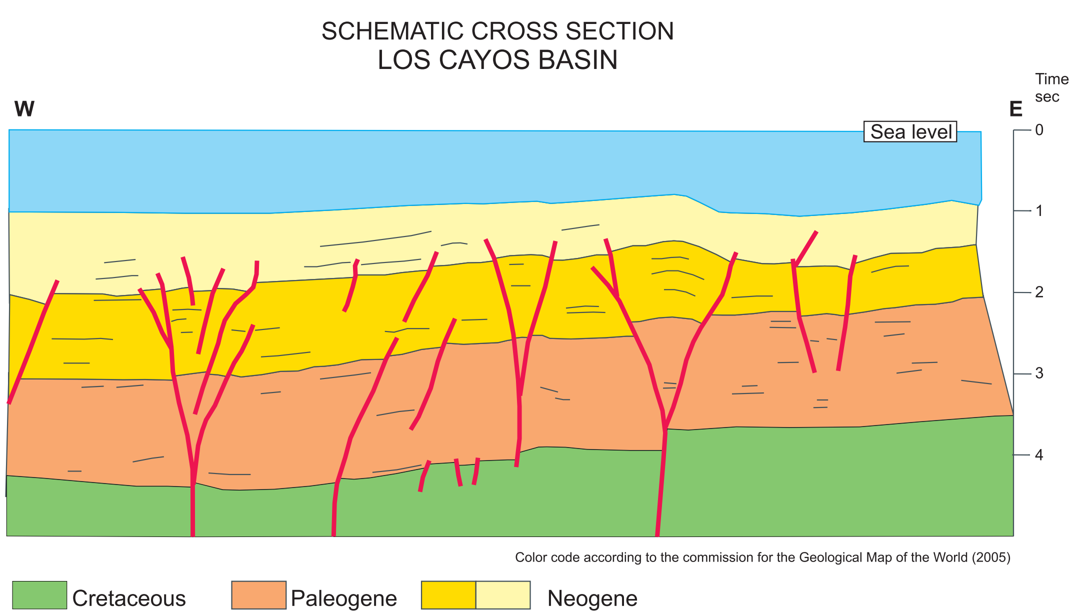
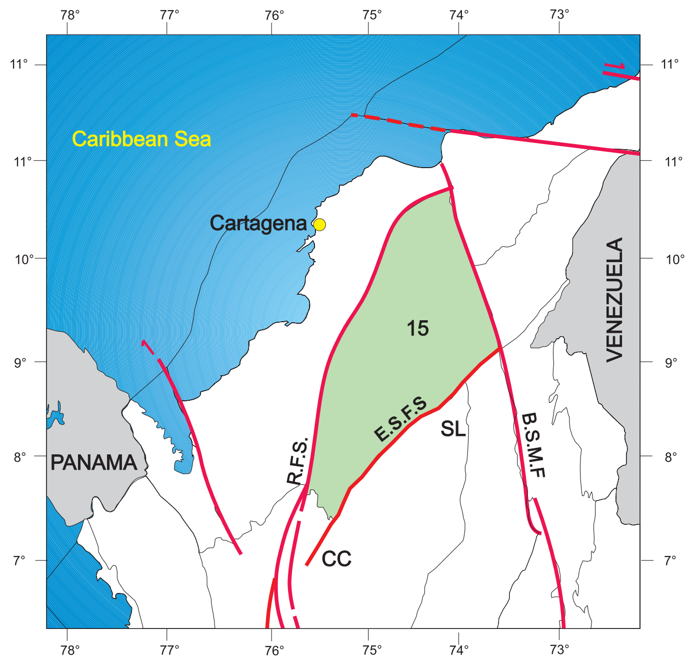


Figure 17. *Los Cayos Basin (14), location and boundaries (see also the figure 4).*

Lower Magdalena Valley Basin (LMVB)

The Lower Magdalena Valley Basin (LMVB) is a triangular transtensional basin bounded to the west and north by the Romeral fault system and to the south and south-east by the metamorphic and igneous complex of the Central Cordillera and the Serranía de San Lucas, a boundary that seems to be a major strike-slip fault system (Espíritu Santo fault system). The eastern limit of the basin is the northern portion of the Bucaramanga-Santa Marta fault system (figure 18). A basement high divides the basin into the northern El Plato and the southern San Jorge sub-basins. General information: Ingeominas, 2006; Montes et al., 2005.



BOUNDARIES

North: Romeral fault system (R.F.S)

West: Romeral fault system (R.F.S.)

South and Southeast: Central Cordillera(CC) and Serranía de San Lucas (SL) Pre-Cretaceous rocks

East: Bucaramanga-Santa Marta fault system (B.S.M.F.)

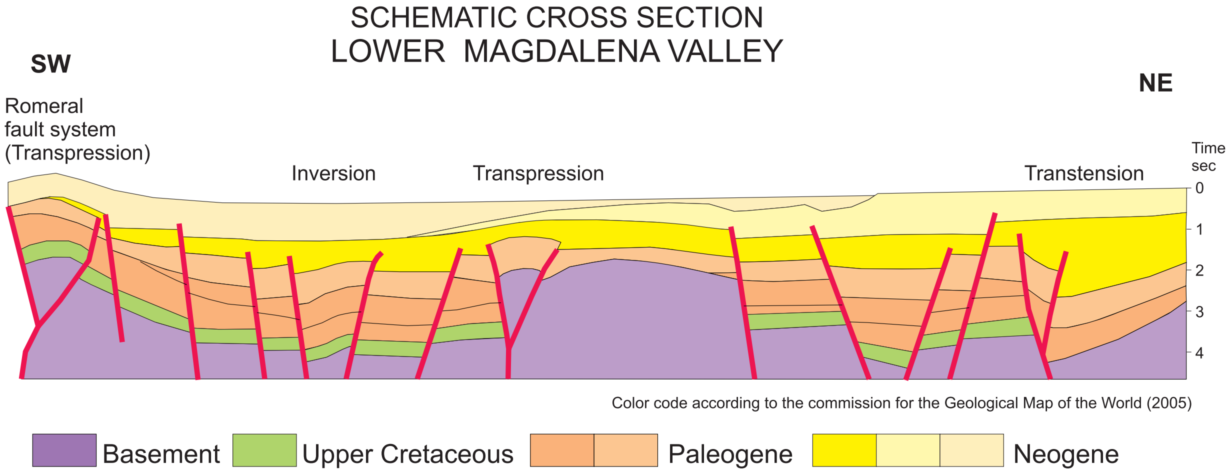
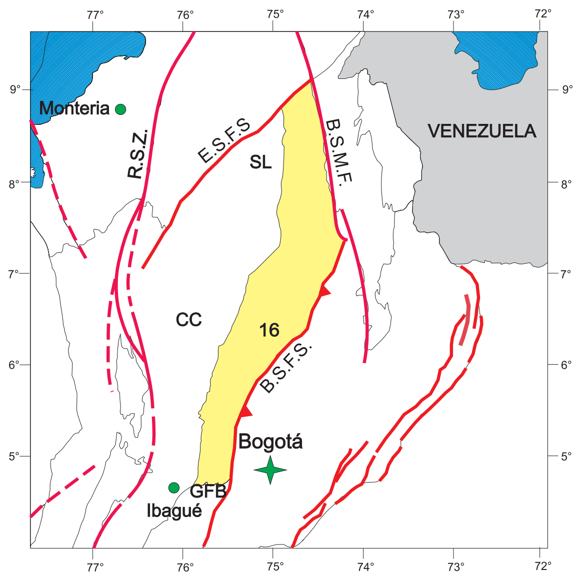


Figure 18. *Lower Magdalena Valley Basin (15), location and boundaries.*

Middle Magdalena Valley Basin

Middle Magdalena Valley Basin (MMVB)

The MMVB correspond to what Kingston et al., 1983 called a poly-historic basin. Structural development took place through different stages linked to the tectonic events of the northwest corner of the South America that happened during Late Triassic, Middle Cretaceous, Early Paleogene and Middle Neogene. The basin stretch along the middle reaches of the Magdalena river and is bounded to the north and south by the Espíritu Santo fault system and the Girardot foldbelt, respectivel. To the northeast the basin is limited by the Bucaramanga-Santa Marta fault system and to the southeast by the Bituima and La Salina fault systems (Llinas, J.C., 2001, La luna Oil, Internal Report). The western limit is marked by the westernmost onlap of the Neogene basin fill into the Serranía de San Lucas and the Central Cordillera basement (figure 19). General information: Gomez, et al., 2005; Gomez, et al., 2003; Rolón and Toro, 2003; Rolón, et al. 2001; Restrepo-Pace, 1999; Schamel, 1991; Barrero and Vesga, 1976; Feininger et al., 1970.



BOUNDARIES

Southeast: Bituima and La Salina fault systems (B.S.F.S.)

North: Espiritú Santo fault system (E.S.F.S)

West: Onlap of Neogene sediments over the Serranía de San Lucas (SL) and Central Cordillera (CC) basement

South: Girardot fold beld (GFB)

Northeast: Bucaramanga-Santa Marta fault system (B.S.M.F.)

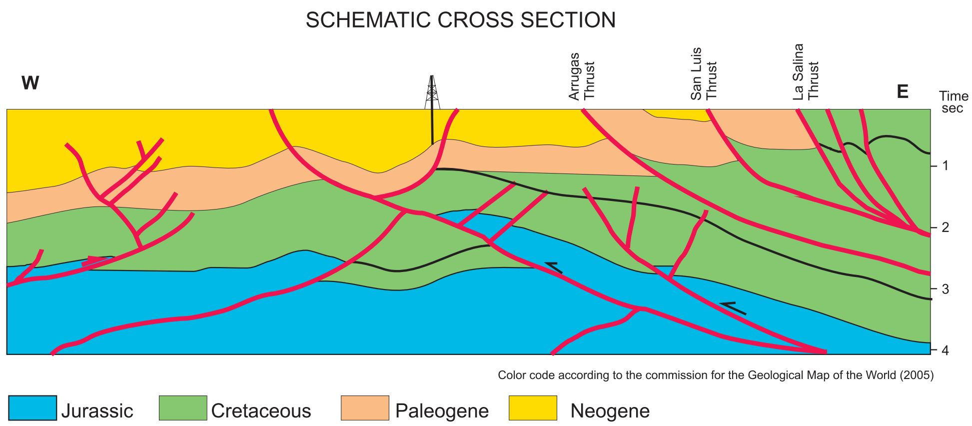
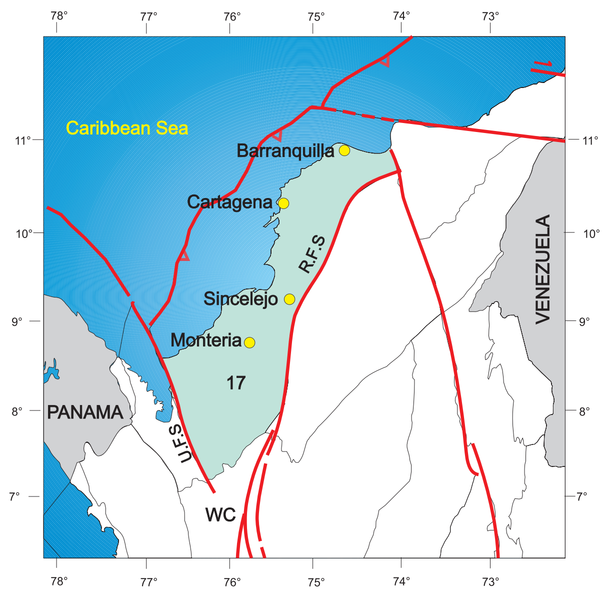


Figure 19. *Middle Magdalena Valley Basin (16), location and boundaries.*

Sinú-San Jacinto Basin

Sinú-San Jacinto Basin/ foldbelt

The Sinú-San Jacinto Basin is located in northern Colombian, and it is the most prolific area in oil and gas seeps among Colombian basins. This under-explored basin limits to the east with the Romeral fault system; to north-northwest with the present Caribbean coast; to the west with the Uramita fault system, and to the south with the cretaceous sedimentary and volcanic rocks of the Western Cordillera (figure 20). The structural development of the basin is linked to the transpressional deformation generated by displacement of the Caribbean Plate. The Sinú portion of the basin is very rich in mud diapirs and oil seeps. General information : Amaral et al., 2003; Duque-Caro, 1984; Mann, 1999; Ruiz et al., 2000; Villamil et al., 1999.



BOUNDARIES

North- northwest: Present Caribbean coast

West: Uramita fault system (U.F.S.)

South: Cretaceous rocks of the Western Cordillera (WC)

East: Romeral fault system (R.F.S.)

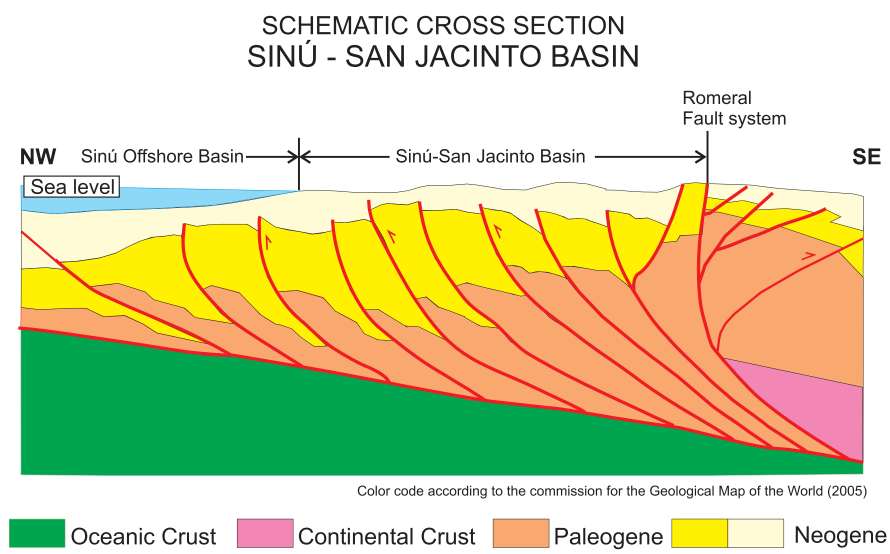
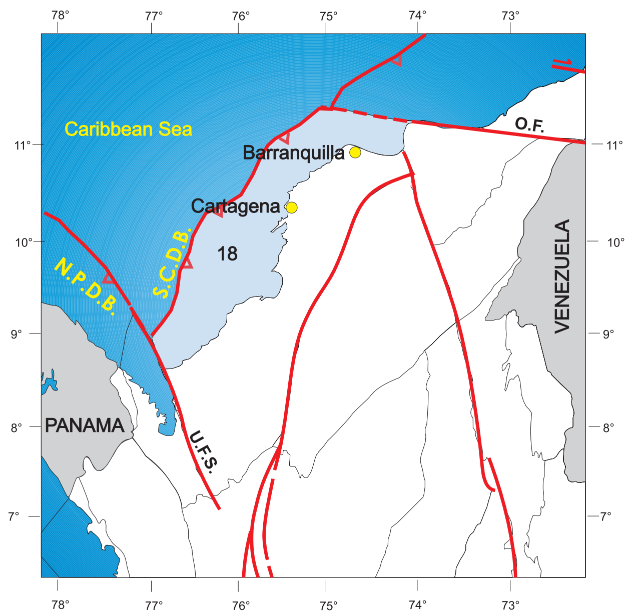


Figure 20. *Sinú –San Jacinto Basin (17), location and boundaries.*

Sinú Offshore Basin

Sinú Offshore Basin/foldbelt

This basin is entirely under Caribbean Sea waters and its structuring consists of a number of northwest verging contractional fault-related folds and associated mud-diapirs. Its northeast limit is the Oca fault; the line separating the frontal thrust from non-deformed Caribbean crust sediments mark its northwestern limit (named South Caribbean Deformed Belt deformation front; figure 21); the southwest boundary is the offshore east boundary of the Urabá Basin and, the southeastern limit the present day shoreline (figure 20). This new limits definition includes the so-called "Sinú Marino" of former basins map of the ANH (figure 3). General information: Duque-Caro, 1984; Amaral et al., 2003; Ruiz et al., 2000; Villamil et al., 1999.



N.P.D.B. North Panama Deformed Belt

BOUNDARIES

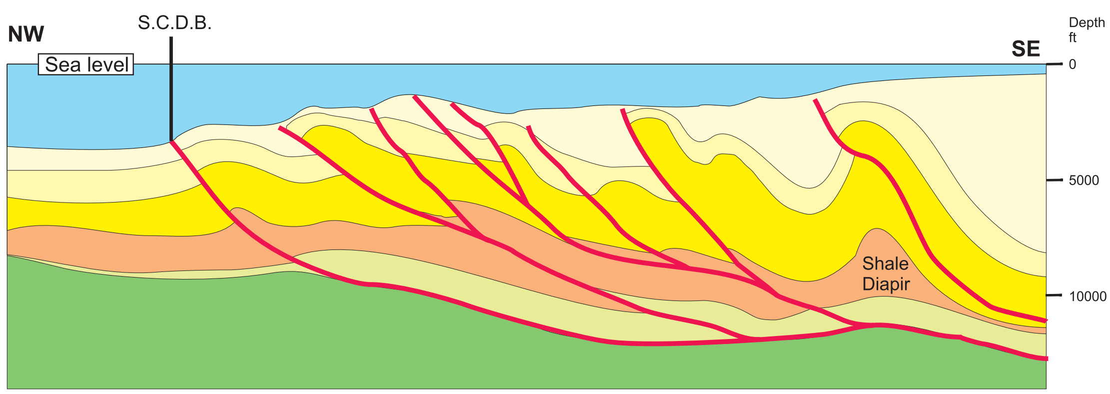
Northeast: Oca fault (O.F.)

Southeast: Present day shoreline

Northwest: South Caribbean Deformed Belt deformation front (S.C.D.B)

Southwest: Uramita fault system (U.F.S)

SCHEMATIC CROSS SECTION
SINU OFFSHORE BASIN



Modified from Amaral, et al., 2003.

Color code according to the commission for the Geological Map of the World (2005)

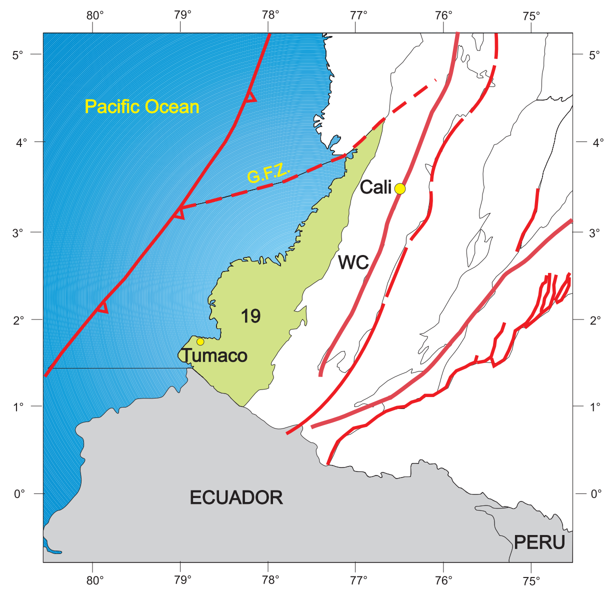
Oceanic Crust | Upper Cretaceous | Paleogene | Neogene

Figure 21. *Sinú Offshore Basin (18), location and boundaries.*

Tumaco Basin

Tumaco Basin

The onshore Tumaco Basin lies in the southwestern region of Colombia. The basin limit to the north with the Garrapatas fault system; to the south it extend as far as the Colombian-Ecuadorian border; the eastern limit goes along the Cretaceous rocks of the Western Cordillera, and the west limit is the present day coastline of the Pacific ocean (figure 22). A Late Cretaceous-Neogene sequence shows gentle folding on top of a basaltic basement. Mud-cored anticlines are common. General information: Cediel et al., 1998; IGAC-Ingeominas, 2001.



BOUNDARIES

North: Garrapatas fault zone (G.F.Z.)

South: Colombian-Ecuadorian border

East: Western Cordillera (WC) Volcanic rocks

West: Coast line of the Pacific Ocean

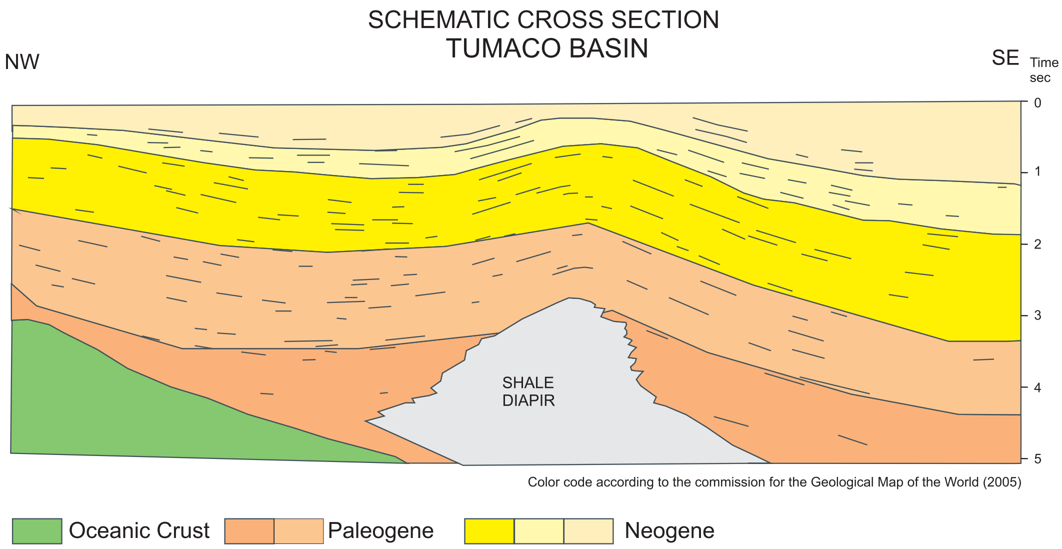
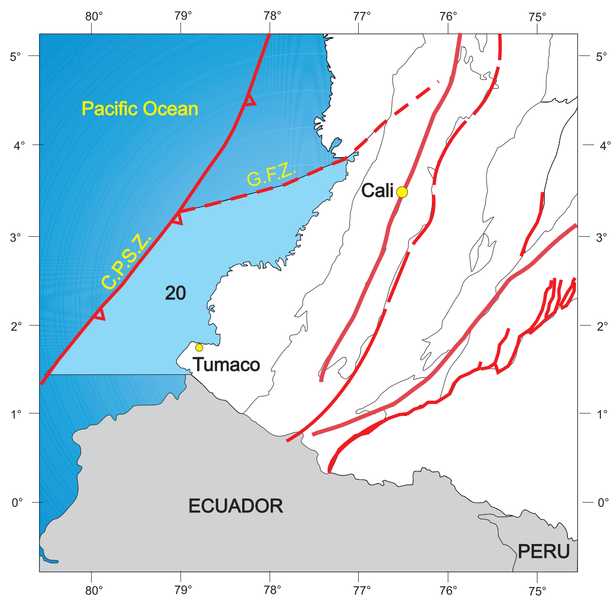


Figure 22. *Tumaco Basin (19), location and boundaries.*

Tumaco OffshoreBasin

Tumaco Offshore Basin

The Tumaco Offshore Basin is located in the southwest marine region of Colombia, under waters of the Pacific Ocean. The tectonic setting of this basin is the forearc of the Upper Cretaceous subduction complex. The limits of this basin are: to the north the Garrapatas fault system; to the south the Ecuadorian border; to the east the present day shoreline, and to the west the inner trench wall of the present subduction zone (figure 23). The basin has a belt of mud-diapirs extending parallel to the shoreline. General information: Cediel et al., 1998; IGAC-Ingeominas, 2001.



BOUNDARIES

North: Garrapatas fault zone (G.F.Z.)

South: Colombian-Ecuadorian border

East: Present shoreline

West: Trench of the Colombian Pacific subduction zone (C.P.S.Z.)

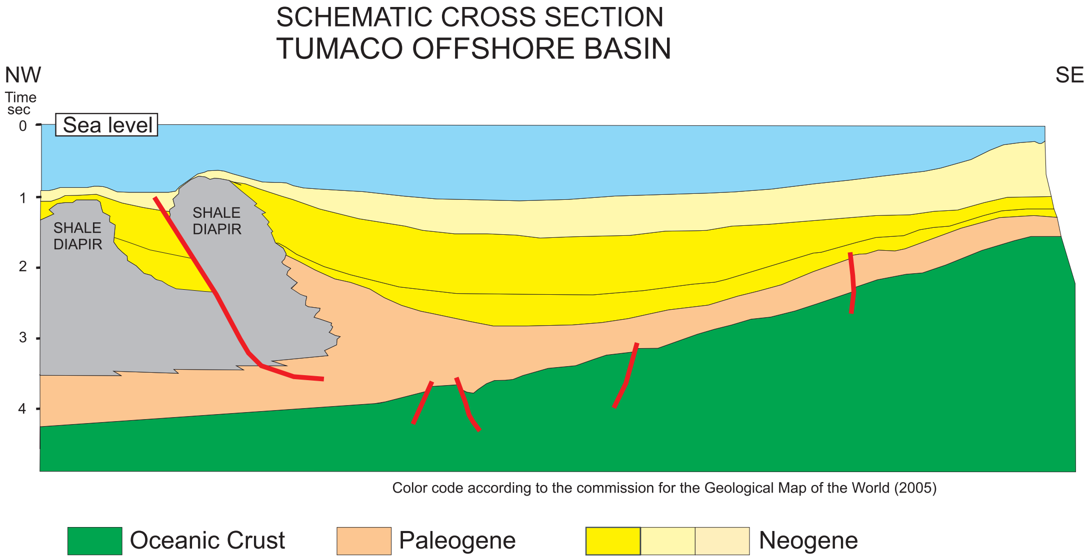
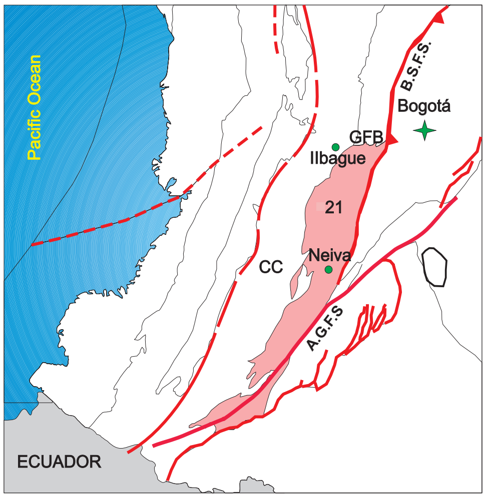


Figure 23. *Tumaco Offshore Basin (20), location and boundaries.*

Upper Magdalena Valley (UMVB)

The UMVB is an intermontane basin located in the upper reaches of the Magdalena river. It is bounded to the east and west mainly by the pre-cretaceous rocks of the Eastern Cordillera and Central Cordillera, respectively, and by the Algeciras-Garzón strike-slip fault system and the Eastern Cordillera foothills thrust system to the southeast. The Bituima and La Salina fault systems and the Girardot foldbelt correspond to its northeastern and northern limits (figure 24). A basement-cored high, called the Natagaima-El pata high, divides the UMVB into two sub-basins: Girardot and Neiva. General information: Buttler and Schamel, 1998; Jaimes and De Freitas, 2006; Montes, 2001; Radic and Jordan, 2004; Ramón and Rosero, 2006.



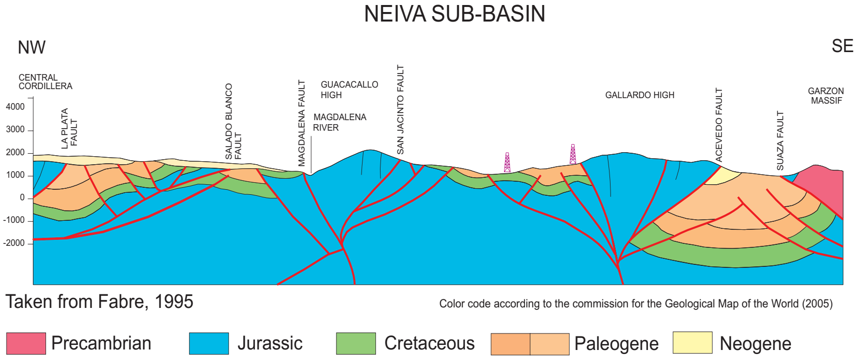
BOUNDARIES

North: Girardot fold belt (GFB)

Southeast: Partially the Algeciras-Garzón fault system (A.G.F.S.)

Northeast: The Bituima-La Salina fault system (B.S.F.S.)

West: Pre-cretaceous rocks of the Central Cordillera (CC)



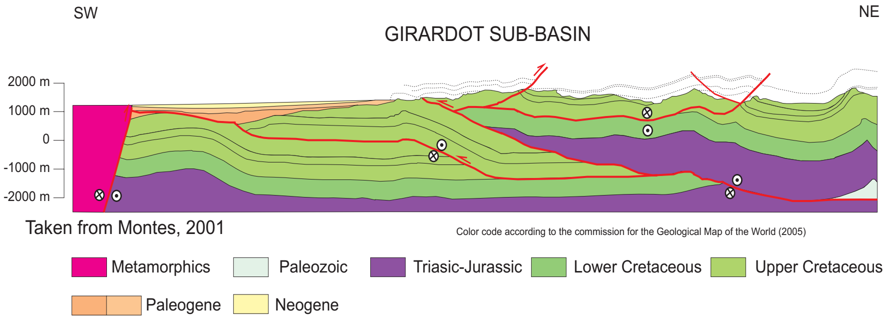
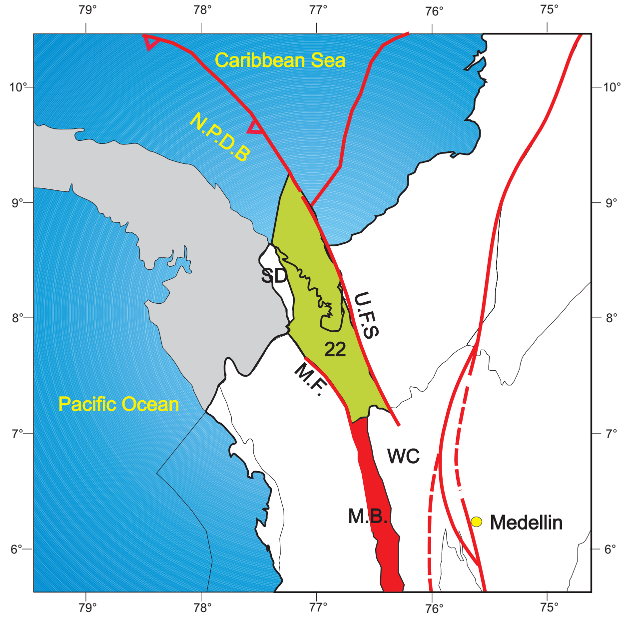


Figure 24. *Upper Magdalena Valley Basin (21), location and boundaries.*

Urabá Basin

Urabá Basin

The Urabá Basin is a rectangular collision-related basin bounded to the east and west by the strike-slip Uramita fault and the Serranía del Darien, respectively, and by the Murindó fault, the Mandé batholith and the Cretaceous rocks of the Western Cordillera to the south-southwest (figure 25). The northern-northwest extension goes as far as the Colombian-Panamá border in the North Panama Deformed Belt. The new boundaries are intended to include both the onland "Urabá" basin and "Urabá Marino" of the former ANH basin map. General information: Geotec, 1988; Ingeominas, 2006; Cediel et al., 1998.



N.P.D.B. North Panama Deformed Belt

BOUNDARIES

North-Northwest: Colombian-Panamá Boundary

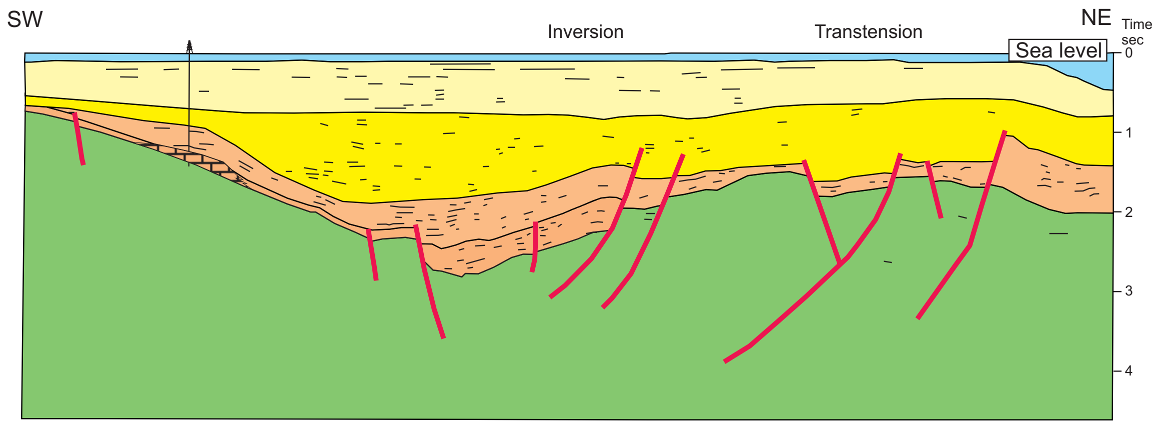
Southwest: Mandé batholith (M.B.) and Murindó fault

East: Uramita fault system (U.F.S.)

West: Serranía del Darien (SD)

South: Cretaceous rocks of the Western Cordillera (WC)

SCHEMATIC CROSS SECTION
URABÁ BASIN



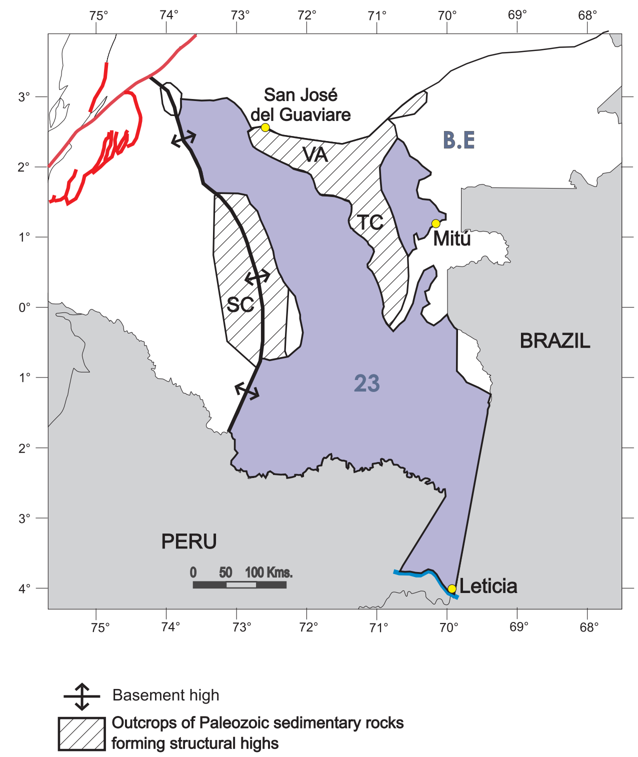
Color code according to the commission for the Geological Map of the World (2005)

Oceanic Crust Paleogene Neogene

Figure 25. *Urabá Basin (22), location and boundaries.*

Vaupés – Amazonas Basin

This new proposed basin is a south-east plunging depression located in southeastern Colombia and bounded to the west and northeast by the Serranía de Chiribiquete and La Trampa-La Mesa de Carurú, respectively, and by the Vaupés arc to the north which is conformed by Lower Paleozoic rocks, forming structural highs. To the north of Mitú, an isolated area covered by Neogene sediments was included in this basin (figure 26). The south-southeastern extension of this basin reaches the Peruvian and Brazilian frontiers and may extend far southward as to join the Solimoes Basin.



BOUNDARIES

North: Vaupés arc (VA)

South-Southeast: Peruvian and Brazilian frontiers

West: Basement high. Serranía de Chiribiquete (SC)

East: La Trampa - Carurú highs (TC)

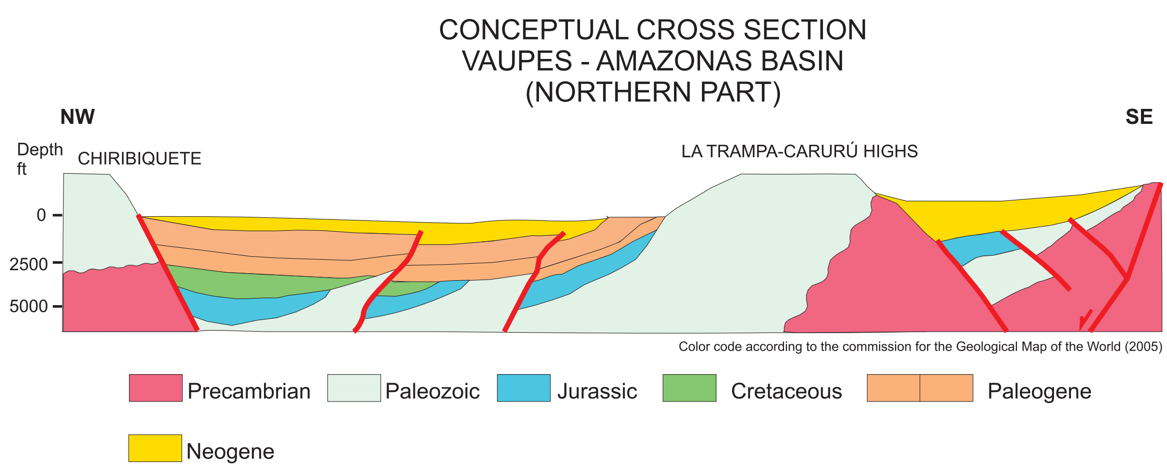


Figure 26. *Vaupés – Amazonas Basin (23), location and boundaries.*

Petroleum Geology of Colombian Basins

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3.1 Caguán - Putumayo Basin

Basin type	Foreland
Oil field discoveries	19
Discovered oil reserves	365 MMBO
Recovered gas reserves	305 GCF

Overview

The Caguán-Putumayo Basin is the northern extension of the Oriente Basin of Ecuador. This basin has an extension of about 104.000 km2, and reserves of more than 365 MMBO have been found to date in 19 oil fields. Exploration in the basin was started by Texaco in 1948. In 1963 this company discovered the major Orito oil field with reserves in the order of 250 MMBO. The existence of a petroliferous system at work is documented by the several oil fields discovered in the basin. Two main structural plays: 1) high-angle reverse fault and, 2) wrench related anticlines account for most of the oil discovered so far. In addition, stratigraphic plays are also important exploration targets.

Petroleum Geology (Figure 27)

- **Hydrocarbon Evidence**

Significant production, one major oil field (Orito), 18 minor oil fields and the presence of giant oil fields in the nearby Oriente basin in Ecuador are the evidence of the exploration potential of this basin. Giant Oil-seeps are active in the northern Caguán area.

- **Source**

Cretaceous limestones and shales from the Villeta Formation, with marine organic matter type II, high petroliferous potential and average TOC of 0.5-1.0 percent represent the best source rocks in the basin. Cretaceous organic shales from the Caballos Formation, with average TOC of more than 0.5% and organic matter type III, is a secondary source of hydrocarbons.

- **Migration**

Two pods of active source rocks within the Cretaceous sequence, located in the western flank of the basin, contributed to the hydrocarbon charge in the Putumayo Basin. Migration pathways show several options. The most likely migration route seems to be west to east along sandstones of the Caballos and

Villeta formations. Vertical migration along fractures and fault zones has also been documented. Expulsion of hydrocarbon started by Late Miocene soon after the formation of the major structures.

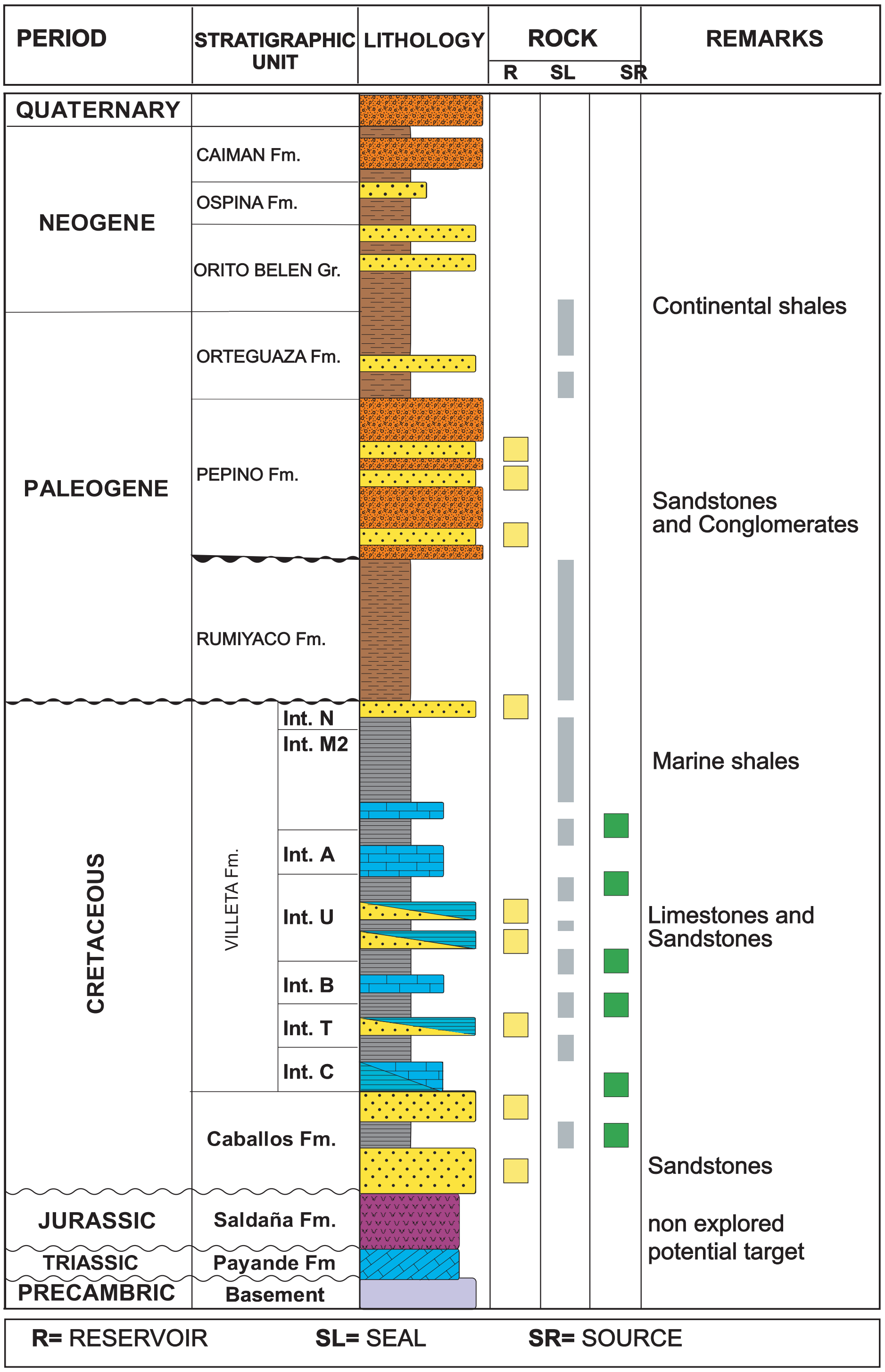

Figure 27. Caguán – Putumayo Petroleum system chart.

- **Reservoir**

Cretaceous sandstones of the Caballos Formation is the main reservoir in the basin with an average thickness of 300 ft depending on paleorelief. Porosities range from 10% to 16% and permeabilities average 50 md.

Secondary reservoirs are found in sandstones of the Villeta Formation and Pepino conglomerates.

- **Seal**

Cretaceous plastic shales of the Villeta Formation are excellent top and lateral seal units. Rumiyaco and Orteguaza shales are also potential seals.

- **Trap**

The main targets are structural traps associated with thrusts and sub-thrusts in the western side of the basin, and up-thrusts in the foreland basin. Additional traps are: pinch-outs, incised valleys, and carbonate buildups.

- **Prospectivity**

Oil fields in the basin are related to structural traps, mainly contractional fault-related folds, and reverse faulting. Additional oil reserves could be found in significant quantities trapped in sub-basement traps, wrench related anticlines, and drapes over basement highs and subtle stratigraphic traps at the eastern flank of the basin. Presence of these traps suggests that large part of the basin still has significant exploration potential.

3.2 Catatumbo Basin

Basin type	Foreland
Area	7,350 km2 / 1,800,000 acres
Wildcat wells	39
Oil field discoveries	11

Overview

The Catatumbo Basin in Colombia is a southwest extension of the Maracaibo Basin. To date, eleven oil and gas fields have been discovered in this basin. Oil, reservoired in Cenozoic and Cretaceous sandstones and limestones, is trapped in faulted anticlines. The Cretaceous and Cenozoic in this basin represent two distinct tectonic and sedimentary settings. Cretaceous rocks are marine sandstones, shales and limestone that represent deposition in a broad shallow sea that extended across northern Venezuela and continued south through Colombia. Cenozoic rocks are fluvial-deltaic shales and sandstones that were deposited in a foreland basin. Overall, reservoir porosity is best developed in Paleogene sandstones. Traps are wrench controlled, faulted anticlines that resulted from strike-slip convergence. Oil was sourced from the upper Cretaceous La Luna Formation and the lower Cretaceous Uribante Group. Oil generation began in the Late Eocene and continues through today. Seventy percent of the reserves were discovered between 1920 and 1950 and were based on surface exploration (mapping of surface anticlines.).

Catatumbo Basin

Most of the remaining hydrocarbon potential in this basin occurs in en-echelon folds associated with the regional left-lateral Chinácota fault system on the western flank of the basin, referred to as the "Catatumbo Flexure" in the northern portion of the basin (figure 8).

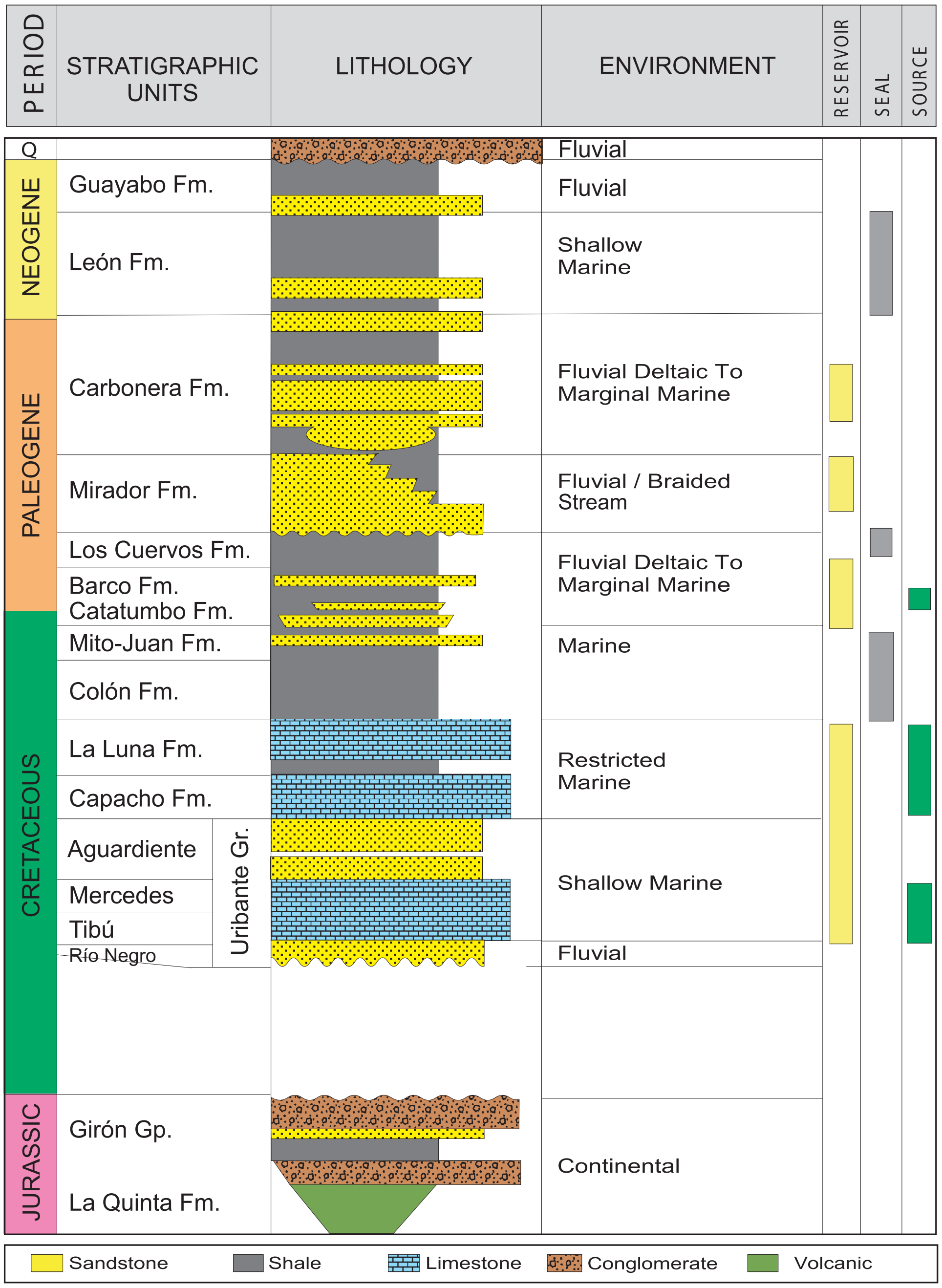

Figure 28. Catatumbo Petroleum system chart.

Petroleum Geology (Figure 28)

- **Source**

Cretaceous-pelitic rocks (La Luna, Capacho, Tibú and Mercedes formations) are widely present throughout the Catatumbo Basin; they are regionally distributed in the Maracaibo Basin and are considered one of the richest hydrocarbon sources in the world. The La Luna Formation is the principal source in the basin and is 200 ft. thick. The TOC ranges between 1.5% to 9.6%, with average 3.8%. The La Luna Formation is currently in the oil window.

- **Migration**

Three distinct migration systems have likely operated to fill the Catatumbo sub-basin traps that were developed in the late Miocene-Pliocene. The lithological character of the Cretaceous sequence, very fine grained sands and homogeneous limestone and shale, favored the development of in-situ oil reservoirs with very little or no hydrocarbon migration. Lateral migration along sandstone bodies and vertical migration along fractures are the two most effective migration pathways.

- **Reservoir**

Main reservoir rocks are Cretaceous shallow water limestones and Cretaceous sandstones (Uribante Group, Capacho and La Luna formations). Deltaic sandstones of Paleogene age (Catatumbo, Barco, Mirador and Carbonera formations) are also good reservoirs. Additionally, fractured basement rocks are also considered to be potential reservoirs.

- **Seal**

Thick marine and non-marine shales in the Cretaceous and Cenozoic sequences form potential seals.

- **Trap**

The Catatumbo Basin shows a wide variety of traps: normal faults with partial inversion, subthrust structures, triangular zones and structures associated to inversion systems are important structural traps. Some oil entrapments within the Paleocene, Barco and Catatumbo formations are considered as indigenous or in-situ. The entrapment and production of Cretaceous oil is basically controlled and associated with the secondary porosity developed by fracturing of the same Cretaceous rock.

- **Prospectivity**

The Catatumbo Basin has been one of the most prolific basins in the country. Commercial hydrocarbon production comes from structures related to asymmetric folds affected by inversion. The western zone of the basin is a fold belt and recent studies in the area indicate potential exploration plays along thrust zones. The main oilfields in the basin are the Rio de Oro, Tibú - Socuavo, Carbonera, Sardinata, Rio Zulia, Petrolea and Puerto Barco. The Catatumbo Basin is a moderately explored basin which has produced more than 450 MMbbl of oil and 500 Gcfg since 1920.

3.3 Cauca-Patía Basin

Basin type	Collision Related
Area	12,800 km2 / 3,200,000 acres
Wildcat wells	5
Seismic coverage	1,000 km
Source Rocks	Chimborazo and Nogales shales
Reservoir Rocks	Chimborazo and Chapungo sandstones
Seal Rocks	Guachinte - Ferreira shales

Overview

The Cauca-Patía Basin lies between the Central Cordillera to the east and the Western Cordillera to the west. The basin is mapped as an elongated geomorphic depression that extends for about 450 km north-south and averages 40 km east-west (figure 9). The basin was developed by collision of an intra-oceanic island arc against the irregular continental margin of the northwestern part of South America. Age relationships of molasse deposits that were folded and thrusted show that diachronous collision was completed from south to north during late Cretaceous to Neogene. The best evidence of the presence of a hydrocarbon system is the Matacea Creek oil seep.

Petroleum Geology (Figure 29)

- **Hydrocarbon Evidence**

Presence of a hydrocarbon system at work is given by the oil and gas shows reported in a few wells drilled in the Cauca Valley area, and by the Matacea Creek oil seep in the Patía region.

- **Source**

Geochemical analyses carried out on 60 samples from 6 surface sections and one oil sample from the Matacea Creek oil seep indicate that the shaly Nogales Formation of Late Cretaceous age and the Eocene Chimborazo Formation have the highest source potential. TOC contents are greater than 2 % for Cretaceous rocks and between 1 and 2 % for the Eocene shales. Organic matter consists of a mixture of kerogene type II and III. In the Patía region the Chapungo Formation is considered a potential source rock.

- **Migration**

Migration of hydrocarbon occurred along sandstone beds of Paleogene age and fractures related to fault zones. Migration started in the Late Miocene and continues to date as demonstrated by the occurrence of fresh hydrocarbons found in the Matacea Creek oil seep.

- **Reservoir**

Several intervals with reservoir characteristics are present throughout the sedimentary sequence of the basin. The main siliciclastic reservoir is the Chimborazo Formation which has porosities of 5 -15 % and average permeabilities of 100 md.

- **Seal**

Top and lateral seals are provided by claystones and shales of the Chimborazo, Guachinte and- Ferreira formations. Nevertheless, seal is the main risk factor in the basin.

- **Trap**

More than 1,000 km of seismic reflection profiles across the basin show the presence of high-side and subthrust anticlines. In the Cauca Valley area imbricate thrust systems provide the main structural traps. Stratigraphic pinch-outs and onlaps are also potential targets.

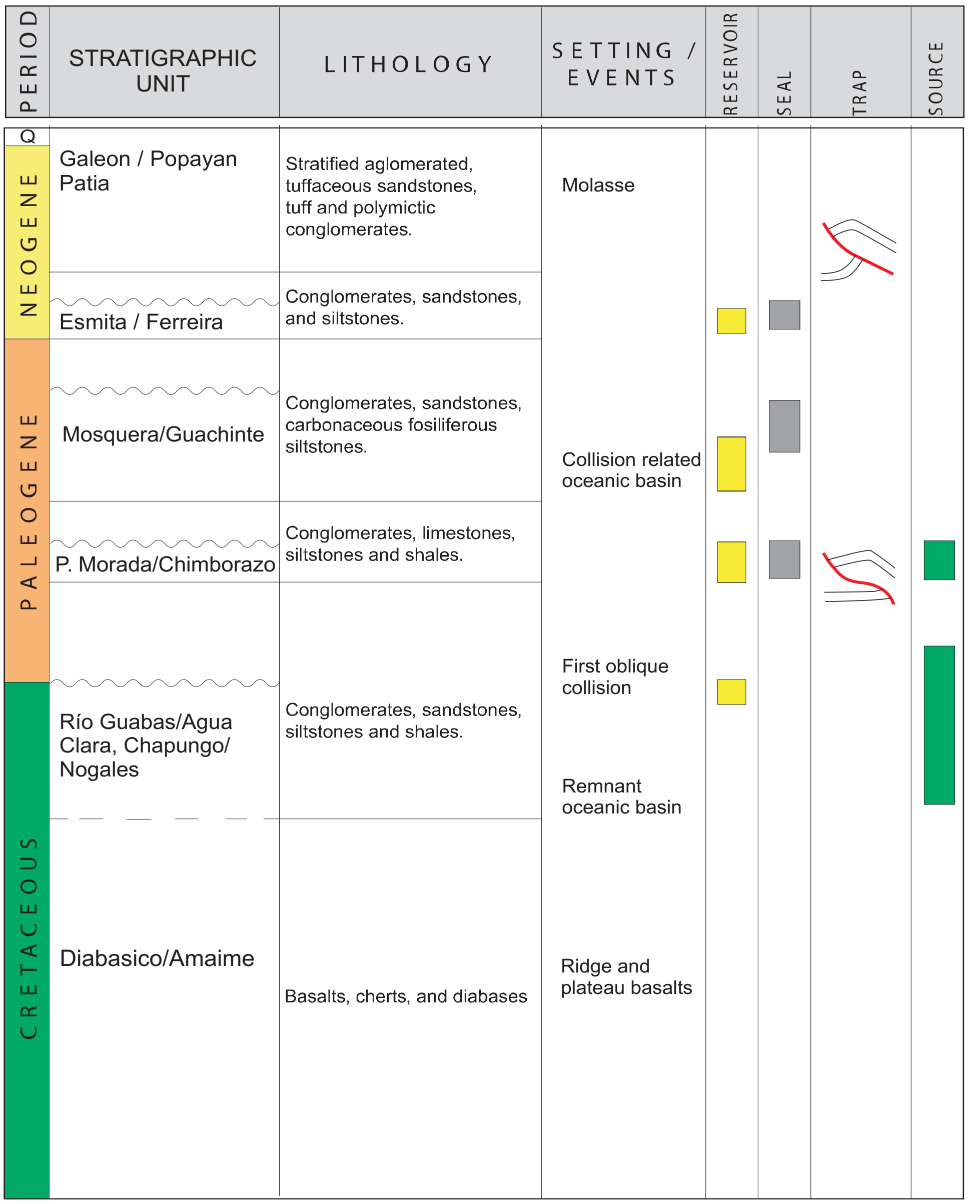

Figure 29. Cauca – Patía Petroleum system chart.

- **Prospectivity**

Structures characterized by large anticline and fault-related traps in the Patía region together with the existence of a proven petroleum system provide attractive targets to explore for liquid hydrocarbon.

3.4 Cesar- Ranchería Basin

Basin type	Intramountain
Area	11,630 km2 / 2,900,000 acres
Wildcat wells	14

Overview

The Cesar- Ranchería Basin in the northeast part of Colombia covers an area of 11,630 km2. Hydrocarbon exploration began in the basin with the well El Paso-1 drilled by the Tropical Oil Company. This limited area is relatively under-explored and contains only 14 wells, most of which were drilled before 1955. High hydrocarbon potential may exist in the relatively unknown subthrust region flanking the Perijá Andes. Two structural plays have been mapped in this area: 1) Cretaceous fractured limestones, 2) Cretaceous and Paleocene sandstones in structural traps.

Petroleum Geology(Figure 30)

- **Hydrocarbon Evidence**

Marginal gas production in the Compae field, and oil shows reported at a number of wells provide clear evidence of a working hydrocarbon system. API gravity ranges from 24º to 37º.

- **Source**

Molino, La Luna, Lagunitas and Aguas Blancas formations show organic richness, quality and maturity that indicate they are effective source rocks. Kerogen type is II / III. Average TOC for the formations are: Molino Fm. 1.0; La Luna Fm. 1.4 and Aguas Blancas Fm. 1.39.

- **Migration**

Secondary migration seems occur during transpressional events that began in Eocene time and lasted until today. Migration pathways are wide fracture systems associated to fault zones.

- **Reservoir**

The main reservoirs are the Lagunitas and Aguas Blancas fossiliferous limestones associated with carbonate ramps. The average gross thickness reported in wells is 500 ft with standard porosity around 5%.

- **Seal**

Cretaceous and Cenozoic plastic shales are the main top and lateral seal rocks in the basin.

- **Trap**

Structural traps associated with subthrust closures in the Perijá region, wrench anticlines in the central region, and flower structures associated to the Oca fault system in the north area, are the most prospective targets.

- **Prospectivity**

In the basin it is possible to identify three main play types:

1. Upper Cretaceous, Aguas Blancas/Lagunitas limestones in subthrust anticline closures.

2. Paleogene/Neogene, Cerrejón and Tabaco sandstones in anticline closures associated to Oca and El Tigre transcurrent faults.

3. Upper Cretaceous, Lagunitas fractured limestones associated to Oca and El Tigre transcurrent faults.

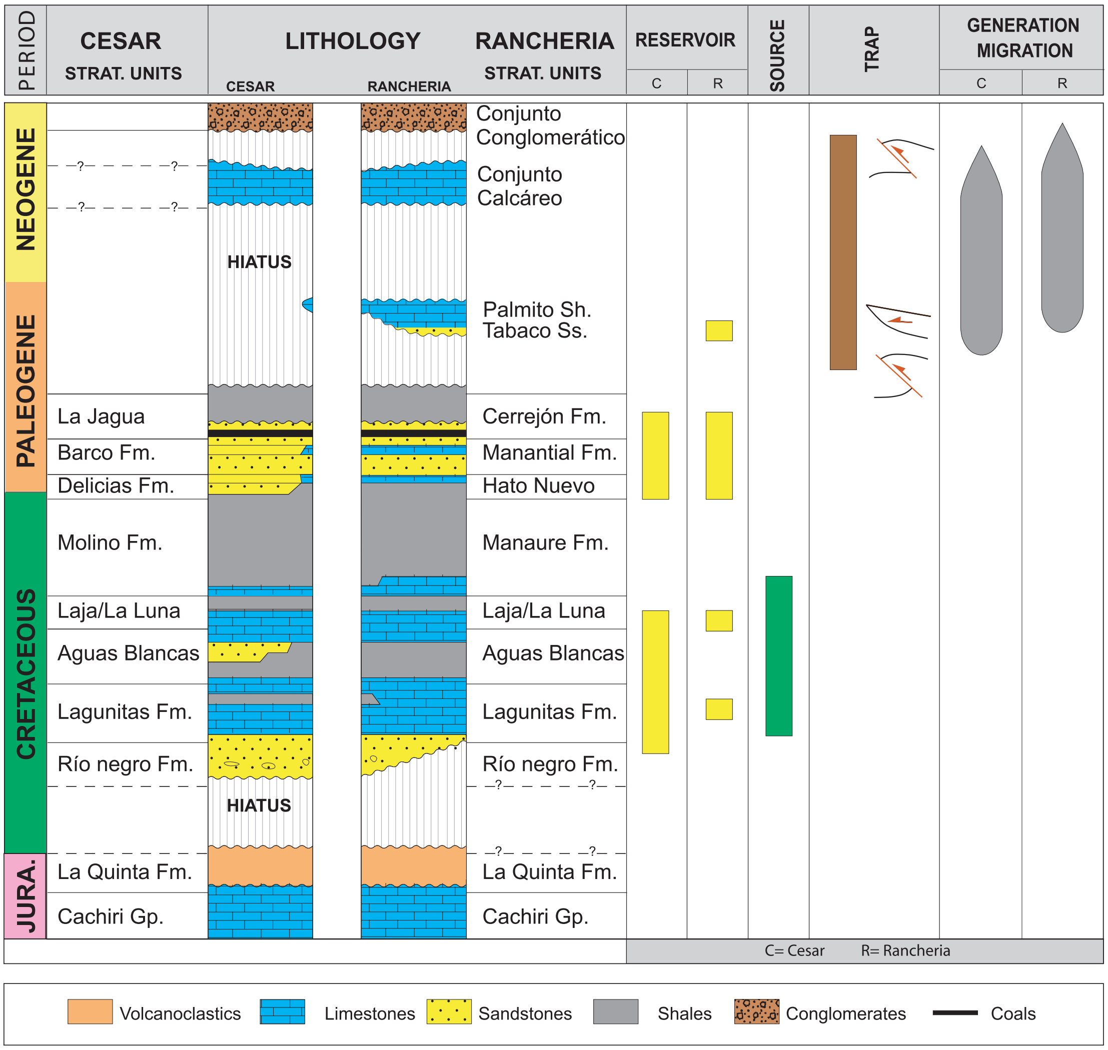

Figure 30. Cesar – Ranchería Petroleum system chart.

3.5 Chocó

Basin type	Fore-Arc?
Source rock	Iró Shale
Reservoir rocks	Iró and Mojarra sandstones
Seal rocks	La Sierra and Itsmina claystones
Wildcats Wells	5

Overview

The Chocó Basin covers about 42,000 km2. To date 5 wells have been drilled, with coverage of 7,000 km2 / well, a density much less than other basins in Colombia. Surface indications for oil and gas have been reported in numerous locations. Subsurface shows of oil and gas were encountered in the Buchadó-1, and Majagua-1 wells.

Petroleum Geology

- **Source**

All the hydrocarbon shows found in the Chocó Basin are believed to have been generated primarily from the Iró Formation (geochemical analyses).

The Total Organic Carbon (TOC) content of the Iró Formation (condensed sections, cherts and shales) has ranks from fair to good.

- **Migration**

Any oil generated must have migrated laterally up dip to the flanks of structures. Long distance lateral migration of hydrocarbons is suggested on the basis of geochemical, stratigraphic and structural data. Vertical migration pathways are associated with fault systems. The critical migration period occurred after deposition of the sealing units about 5 Ma, and continues to date.

- **Reservoir**

Carbonate and siliciclastic rocks from the Iró and the Mojarra formations (Middle Miocene) are the major potential reservoir rocks. Naturally fractured cherts are abundant in the basin and are related to faulting.

- **Seal**

Sealing rocks occur throughout the sedimentary column, represented by clay units. These units are homogeneous, laterally continuous, with excellent ductile properties. The La Sierra (Oligocene) and Itsmina (Lower Miocene) formations are the regional seals.

- **Trap**

Several basement structural highs, mud-cored anticlines, diapir flanks, thrust anticlines, normal fault roll-overs, stratigraphic geometries, and highly fractured carbonates and cherts along fault zones are all potential traps.

- **Prospectivity**

Geochemical data indicate the existence of the Iro-Mojarra (?) petroleum system. TOC content, kerogene type II and III, and Hydrogen Index indicate a good oil prone source rock.

Oil generated may have migrated and been trapped in large mud-cored anticlines, roll-overs associated with listric normal faults and large high-side closures in fault propagation folds.

3.6 Eastern Cordillera

Basin type	Inverted Graben / Fold belt
Area	60,000 km2 / 14,800,000 acres
Field discovered	10 (8 oil fields - 2 gas field)
Wildcat wells	38
Discovered Oil	1,700 MMBO

Overview

The Eastern Cordillera Fold Belt covers an area of about 60,000 km2. It is located between the Magdalena River Valley and the Llanos Cenozoic Foreland Basin. In the present work, the previous boundaries have been slightly modified to include in both sides, the frontal thrust of the fold belt. Therefore, the so called eastern and western foothills which contain the giant Cusiana and the major Provincia oil fields located in the hangingwall of the frontal thrusts, are considered here as a part of the Eastern Cordillera basin.

The beginning of the exploratory process in the basin was oriented to confirm accumulation in anticline structures located in the surrounding areas of Tunja, where multiple oil seeps were found. During the last three decades, drilling has been mainly oriented to the exploration of structural traps on the foothills. During the Triassic-Jurassic and late Cretaceous, tensional/transtensional stresses, produced a system of asymmetric half-graben basins filled continuously with alternate marine and near shore to continental deposits. The deformation of these deposits occurred as a succession of events. The first event of late Eocene-Early Oligocene age generated an imbricated system. The imbricated system was eroded and covered by upper Oligocene deposits. A subsequent transpressional event during Miocene to Pleistocene reactivated pre-existing thrust faults and re-folded the structures concomitant with the uplift of the Cordillera.

Petroleum Geology (Figure 31)

- **Hydrocarbon Evidence**

Five decades of exploration history in the basin has lead to the discovery of about 1,700 MBO, 2.0 TCFG and a total of 10 fields, including the giant Cusiana and Cupiagua fields, and the large gas-condensate Gibraltar discovery.

Eastern Cordillera

- **Source**

Two condensed sections of Mid- Albian and Turonian age, deposited during worldwide anoxic events, are considered the main source. In addition, less important source rocks are believed to be present in the lower and upper Cretaceous. Main hydrocarbon generating sources contain T.O.C. values between 1.0 and 3.0 % and kerogen types I and II.

- **Migration**

The first generation pulse occurred during the Late Cretaceous, but most of the petroleum generated seems to be lost because of the lack of traps at that time. A second pulse occurred from the Miocene to recent times, and it is responsible for filling the giant traps in both foothills.

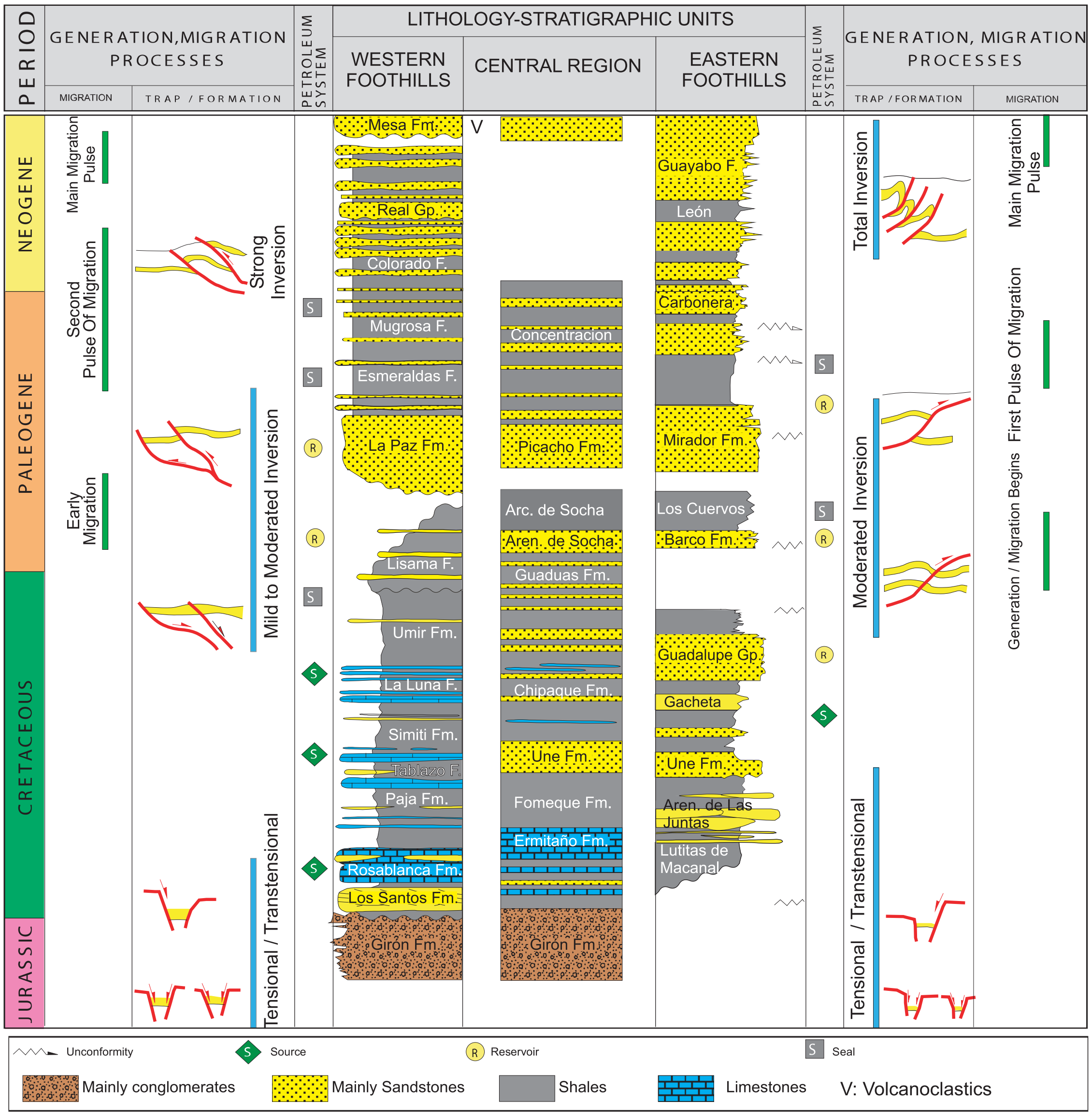

Figure 31. *Eastern Cordillera Basin Petroleum system chart.*

- **Reservoir**

The most important petroleum reservoir rocks were deposited during Albian and Cenomanian time and Paleogene siliciclastic units with a wide range of petrophysical properties: average porosities between 5-10 % and permeabilities in the order of 4-100 md.

- **Seal**

The seals for the Paleogene sandstone reservoirs consist of interbedded shales. The regional seal for the Cretaceous reservoirs are thick shales of marine origin.

- **Trap**

The main structural features are basement involved reverse faults, resulting from the inversion of pre-existing normal faults, contractional fault-related folds and duplex structures.

- **Prospectivity**

The Neogene deformation of sediments in the basin was probably related to strike-slip motions. It is most likely that future discoveries will be associated with traps formed by transpression. Fault-bend folds, fault propagation folds and triangle zones are the main objectives in the Eastern Cordillera. A potential play in the axial zone is related to accumulation against salt domes, and non-conventional gas plays associated to coal beds.

3.7 Eastern Llanos

Basin type	Cenozoic Foreland
2D seismic shot	> 96,000 km
Wildcat wells	260
Number of discoveries	68 oil field, 2 giant, 1 major field

Overview

The Eastern Llanos Basin is located in the Eastern region of Colombia. Geomorphologic boundaries are the Colombian-Venezuela border to the north, Macarena high and Vaupés Arch to the south, Guaicaramo fault system to the west, and Guyana Shield to the east. (figure 14)

The evolution of the basin started in the Paleozoic with a rifting phase. Siliciclastic sediments were deposited over the crystalline Precambrian basement, from Triassic to Late Cretaceous the basin was the eastern shoulder of a major rift system.

Since the Maastrichtian to Paleocene, this basin became a foreland. From Miocene to recent times the basin has been repository of thick molasse deposits. Cretaceous source rocks range from immature to marginal mature within the region to the east of the frontal thrust. Main reservoirs are siliciclastic units of Late Cretaceous and Paleogene age. Analysis of the individual components of the migration systems within the basin is complicated by thinning of the stratigraphic section; and the development of more sand-prone facies towards the Guyana Shield.

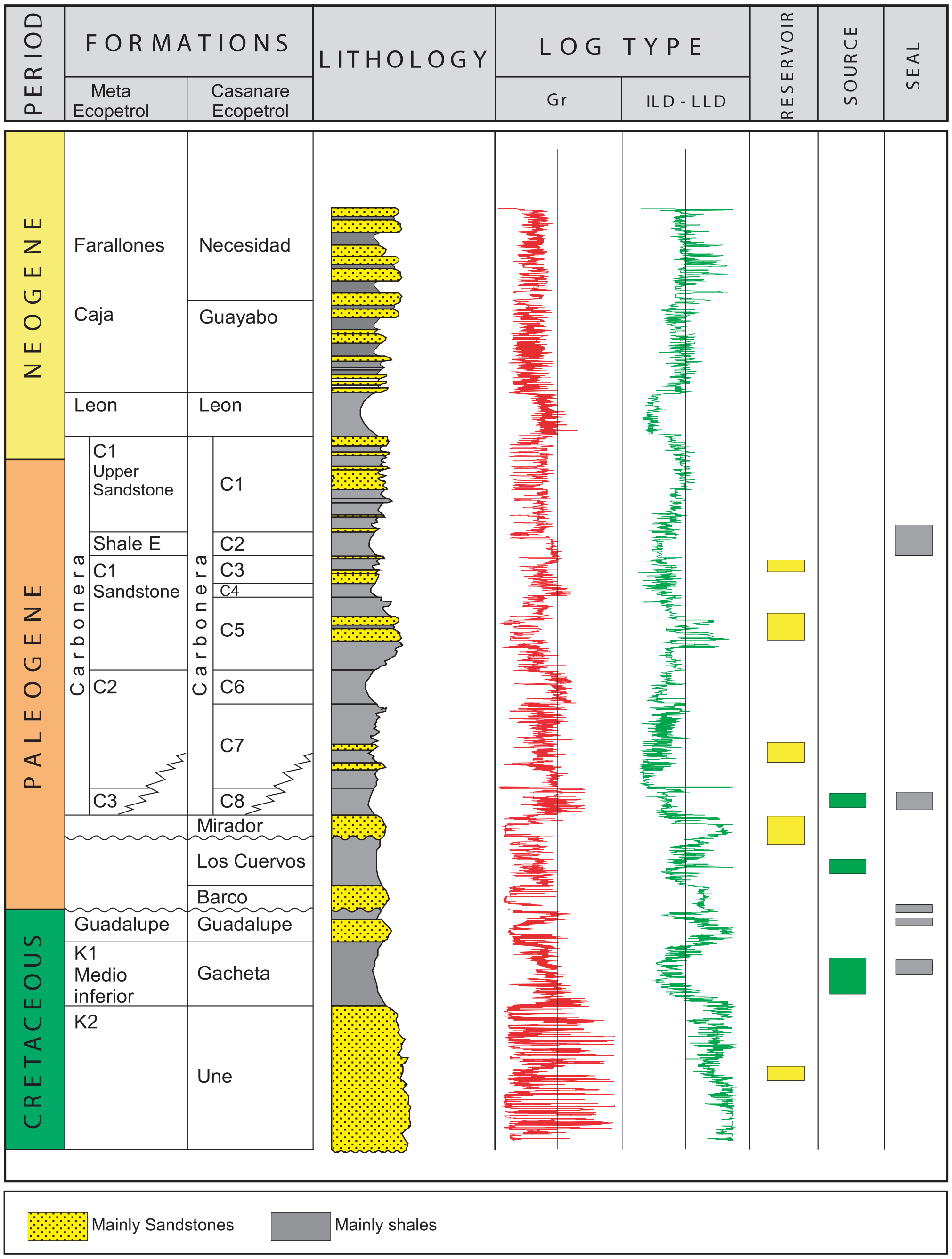

Figure 32. *Eastern Llanos Basin Petroleum system chart.*

Petroleum Geology (Figure 32)

- ### Hydrocarbon Evidence

More than 1,500 MMBO of recoverable oil is officially documented. Two giants, (Caño-Limón and Castilla) three major (Rubiales, Apiay and Tame Complex), and more than fifty minor fields have been discovered.

- ### Source

Source rocks for the Llanos Foreland Basin are in fact located beneath the east flank of the Eastern Cordillera. Mixed marine-continental shales of the Gachetá Formation with kerogen type II and III, TOC ranging from 1-3% and 150-300 ft of effective thickness are the main source.

- ### Migration

Two pulses of migration have been documented. The first one during the Upper Eocene-Oligocene. The second pulse of migration started in Miocene time and is continuing at the present.

- ### Reservoir

The Paleogene Carbonera (C-3, C-5, and C-7) and Mirador sandstones are excellent reservoir units. Within the Cretaceous sequence several sandstone intervals are also excellent reservoirs. Without exceptions, sedimentary thickness increases in an east to west direction. Porosity decreases in the same direction from 30% to near 10%. Pay thickness varies from a few feet up to 180 feet, depending on the location of the well within the basin. API gravity ranges from 120 to 42º.

- ### Seal

The C-8 unit of the Carbonera Formation has been traditionally considered as the regional seal of the basin, but because of its extension the best seal is the Carbonera C-2 Unit. The Carbonera even numbered units are recognized as local seals as well as the Cretaceous Gachetá and Guadalupe formations that may be self-sealant.

- ### Trap

Exploration drilling has been concentrated in normal, up-to-the basin (antithetic) faults. Poorly tested reverse fault anticlines, low-relief anticlines and stratigraphic traps (pinchouts, paleohighs, channels, etc.) are all high potential exploration targets.

- ### Prospectivity

This basin has been moderately drilled and subtle stratigraphic traps have not been deeply studied. Potential areas for hydrocarbon accumulation are located in the southern and eastern portion of the basin where pinch-out of reservoirs are affected by meteoric water forming hydrodynamic traps. The southwestern part, south of the Castilla Field, is also a highly prospective area.

Guajira

3.8 Guajira

Basin type	Transtensional
Area	12,600 km2 / 3,110,000 acres
Wildcat wells	18
Gas discoveries	Ballena (1.5 TCF) and Riohacha (86.5 GCF)

Overview

The Onshore Guajira Basin covers an area of 12,600 km2 and is located in the northernmost part of Colombia. The lower Guajira Basin is the result of a releasing step-over of Cuisa-Oca transcurrent fault systems, thus generating a transtensional margin basin. North of the Cuisa Fault, the upper Guajira is structurally related to rifting that occurred north of Maracaibo Lake. Exploratory drilling started with the Rancheria-1 well, spudded in 1948. To date, only 18 wildcats have been drilled with two gas fields discovered.

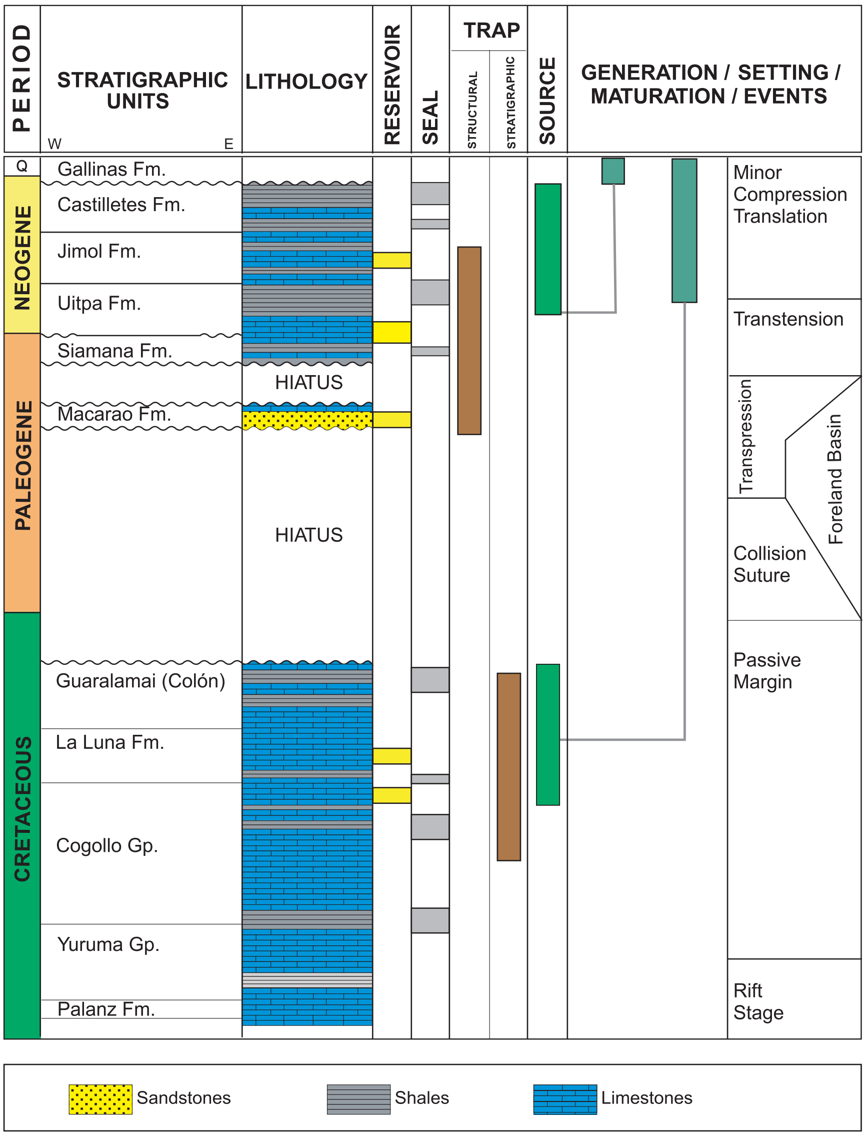

Figure 33. *Guajira Basin Petroleum system chart.*

There is a proven gas generation-migration system within the basin. Migration is enhanced by structural geometry, which focuses migration paths from a thermogenic gas source sitting offshore. There are several documented developments of porous carbonate buildups on horst blocks.

The two main plays are the Paleogene basal sandstone on basement with an onlap/pinchout component and the Miocene carbonate buildups. The Ballena and Riohacha fields are within this area and produce from the carbonate play.

Petroleum Geology (Figure 33)

- **Hydrocarbon evidence**

It is proven by the two gas fields discovered in the basin. Turbiditic sandstones with average porosities of about 17 % are the main targets.

- **Source**

Cretaceous Colon, La Luna, Cogollo shales and the Neogene Castilletes Formation contain kerogen type II and are considered good oil source rocks. Organic matter of Paleogene-Neogene source rocks is strongly gas-prone. The Neogene Castilletes Formation has TOC values ranging from 1 5-2.0 % and kerogen type II and III.

- **Migration**

Most of the structures were formed during Late Paleogene-Early Neogene. Secondary migration of hydrocarbon most likely occurred soon after the first phase of structur¬ing by Late Neogene.

- **Reservoir**

Siliciclastics and carbonates are important reservoirs in the basin. Neogene limestones of the Uitpa and Jimol formations have very good moldic porosity and net pay thickness up to 100 ft. In addition, fractured basement can also be considered as a potential reservoir (e.g. Venezuela, La Paz –Mara fields.)

- **Seal**

Top and lateral seals for Cretaceous reservoirs in the Guajira are adequate where Paleocene and lower Eocene shales are present. Base seal for Paleogene-Neogene reservoirs is variable.

- **Trap**

Several potential structural traps of Neogene age are the result of deformation generated by the Cuisa and Oca faults. Main stratigraphic traps are onlaps and truncations against basement highs. Carbonate mounds are very important trapping geometries.

- **Prospectivity**

The PGG-1 Well (Venezuela) drilled carbonates of the La Luna Formation saturated with oil, thus documenting the existence of a hydrocarbon system in the southeastern corner of the upper Guajira Basin. The generation pod is located to the east of the well in the Cosinetas Basin. Highly prospective structural traps exist in the western flank of the Cosinetas Basin in the upper Guajira. Structural and stratigraphic traps in the lower Guajira have good exploration potential. Oligocene carbonates, fractured by the Oca Wrench System, are the main exploratory target.

Proved Plays: Lower Miocene sandstones and limestones and middle Miocene turbidites.

Unproved Plays: Wrench-Related structures associated to Cuisa and Oca faults. Onlaps and truncations, imbricated thrust sheets and Oligocene carbonate stratigraphic plays and fractured basement.

3.9 Guajira Offshore

Basin Overview

The Guajira offshore Basin is the northernmost sedimentary area of Colombia. It extends from the northernmost point of the Guajira Peninsula to the mount of the Magdalena River in the southwest.

Shallow offshore is considered to have water depths from 0-600 feet. Source rock could be the Castilletes Formation deposited in the deeper and more subsident part of the basin. The main reservoir rocks are carbonates buildups, a Paleogene basal sandstone and submarine fan turbidites. Migration of hydrocarbon from the deep offshore is enhanced by the structural configuration.

Hydrocarbon accumulation has been proven in the shallow offshore (0'-600') by production in the Chuchupa gas field. In addition, westward of Santa Ana-1 well geochemical analyses on offshore piston cores, resulted in the identification of thermogenic gas and oil in such samples.

At least three plays are present over the area. The giant Chuchupa gas field produces from the basal sandstone play. The carbonate play is producing in the Ballena gas field. The deep offshore greater than 600ft of water is very probable the area for the Miocene fan play.

Petroleum Geology

- **Source**

Oil and gas was found in piston cores offshore Guajira (Texaco program 1999). The main source rock in the area could be the offshore extension of the Castilletes Formation deposited in the deeper and more subsident part of the basin. A Cretaceous or even a kimmerigdian source rock could be present, in the deep offshore area, north of the Cuisa Fault.

- **Generation and Migration**

Generation and migration of hydrocarbons is enhanced by structural configuration which focuses migration paths from an early thermogenic source in the deep offshore toward the Chuchupa, Ballena and Riohacha reservoirs.

- **Reservoir**

Two main reservoirs types have been documented in the area: 1) carbonate buildups, a reservoir type which produces gas in the Ballena and Riohacha fields and, 2) the siliciclastic reservoirs composed of the Paleogene basal sandstone, producing in the Chuchupa gas field, and the submarine fan sandstone which extends to the deep offshore.

- **Seal**

Seal in the basin is provided by thick sequences of Paleogene and Neogene shales.

- **Trap**

Structural and stratigraphic traps are abundant in the basin. Roll-overs produced by listric normal faults provide excellent large trapping structures. In addition, drapes over basement highs, carbonate buildups and pinchouts / onlaps are good combination traps.

- **Prospectivity**

The fact that large quantities of gas have been storaged in two main types of plays (Ballena-Chuchupa-Riohacha) and large structures are present with an excellent operation conditions, together with a growing demand of gas in the nearby countries, are good reasons to rank this area as highly prospectivity.

3.10 Los Cayos Basin

Basin type	Transpressional
Area	73,500 km2 / 18,160,000 acres
Discovered oil reserves	None
Wildcat wells	none

Overview

Colombia has an area of 589,560 km2 in the Caribbean Sea. Los Cayos Basin covers an extension of approximately 73,500 km2. The San Andres and Providence archipelago, located 770 km northwest of the Colombian mainland is comprised of the islands of San Andres, Providence and Santa Catalina within the basin.

Petroleum Geology

- **Hydrocarbon evidence**

This is given by oil shows in wells drilled in the nearby area, and oil slicks related to basement highs.

- **Source**

Source rocks are not well documented, but the occurrence of oil shows is an evidence of their existence.

- **Migration: Unknown.**
- **Reservoir**

Siliciclastic Eocene deposits and Miocene-Oligocene reefal limestone. Porosity for siliciclastic rocks could be around 25%, and, 10% for limestone.

- **Seal**

Reported Oligocene-Miocene shales are potential seals.

- **Play Trap**

Structural domes and normal faults. Pinch-outs and carbonate build-ups are potential stratigraphic traps.

- **Prospectivity**

No commercial hydrocarbon discoveries have been reported up to date. However, oil shows indicate exploration potential. Structural and stratigraphic traps are identified in seismic profiles.

3.11 Lower Magdalena Valley

Basin type	Transtensional
Area	41,600 km2 / 10,280,000 acres
Wildcat wells	117
Tested oil reserves (Dec/05)	71 MMbbl
Seismic	20,300 km
Well Coverage	145 km2 / well
Oil field discoveries	17

Overview

The Lower Magdalena Basin is located in the northwest of Colombia where oblique subduction along the Romeral fault system has produced transpressional and transtensional deformation since late Cretaceous to present day. The Lower Magdalena Basin is limited to the northeast by the Bucaramanga - Santa Marta fault system; to the south by the Central Cordillera and to the west by the Romeral fault system (figure 34). This basin is subdivided by three structural elements that have controlled sedimentation since Eocene to late Miocene. These structural elements are: The Plato sub-basin to the north, the Cicuco Arch in the central part, and the San Jorge sub-basin to the south.

Petroleum Geology (Figure 34)

- **Hydrocarbon Evidence**

Abundant oil and gas seeps are evidence of the existence of a prolific Petroleum System at work.

- **Source**

Early Miocene shales (Lower Porquero Fm.) have been recognized as the main source of hydrocarbons in the basin. These shales are of great thickness, rich in organic matter and kerogene type II. The Cienága de Oro Formation has an upper interval with fair-to-rich content of organic matter, type - III, within the oil window in the deepest areas of the basin. This interval could be considered as deposited during a maximum flooding event. The available source rock data suggests a pod of active source rock; probably of Cretaceous age; coinciding with the areas of greater sediment depth.

- **Migration**

Pods of active source rock in generation/expulsion phase are present in an extensive area in the so-called Plato sub-basin; between the wells Guamito-1 to the northeast and Pijiño-1 to the south. API gravity for oil generated within the basin varies between 30° to 52°. The sulfur content is very low; while the paraffin

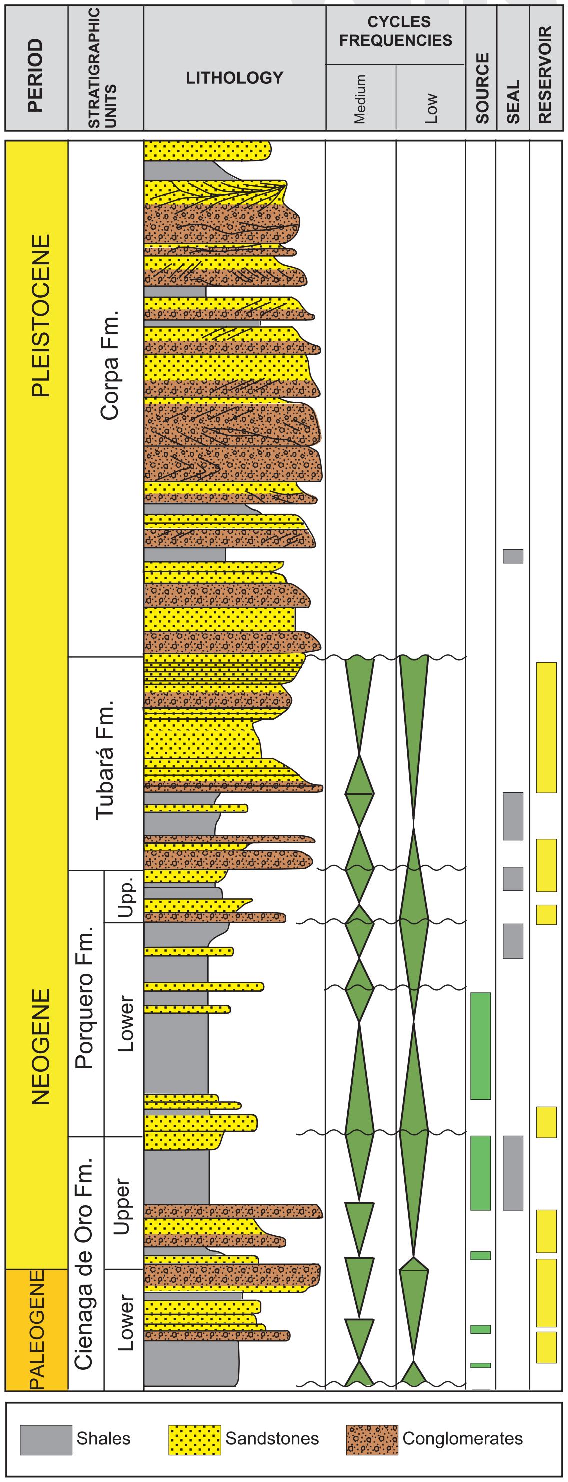

Figure 34. *Lower Magdalena Valley Basin Petroleum system chart.*

concentration is relatively high. Various geochemical parameters indicate that the majority of oil originated in a relatively dioxic proximal siliciclastic environment. Four different migration pathways have been proposed: 1) The Cicuco-Boquete area. 2) Momposina area. 3) Guepaje area and 4) Apure-region. Migration most likely happens along network of fracture and fault planes.

- **Reservoir**

Oligocene sandstones and limestones (Cienaga de Oro Formation) are the main reservoirs in the basin. The gross thickness is 300 ft, with an average porosity of 15%.

- **Seal**

Shales of the upper Porquero and Cienaga de Oro formations deposited during a period of rapid subsidence, have excellent physical characteristics as a sealing unit. The deep-water shales are the regional top seal for the under-laying reservoir rocks. The younger Tubará Formation (Middle Miocene to Lower Pliocene) is also a sealing unit.

- **Trap**

Diverse structural trap types highlights the basin potential, among others: structural traps associated with high-side closures in contractional faults, anticline closures in the footwall of normal faults, structures related to flower geometries generated by transpression, roll-overs in the hanging-wall of listric normal faults, all of them are important structural exploration targets in the basin. Stratigraphic traps are also of great economic impact, since production from carbonates has long been established and submarine fan turbidites are also prospective.

- **Prospectivity**

Presence of oil fields and abundant oil seeps, together with a great variety of structural traps and recent generation from pods of active source rock in deep synclinal structures indicate very good potential for discovery of new reserves.

3.12 Middle Magdalena Valley

Basin type	Poly-historic, Rift to Broken Foreland
Area	34,000 km2 / 7,900,000 acres
Wildcat wells	296
Oil field discoveries	41
Discovered oil reserves	1,900 MMBO
Discovered gas reserves	2.5 GCF

Overview

The Middle Magdalena Basin is located along the central reaches of the Magdalena River Valley between the Central and Eastern Cordilleras of the Colombian Andes. The exploratory process has been oriented mainly towards the identification of structural traps in the Paleogene sequences. Stratigraphic subtle traps have not adequately been studied yet. The sedimentary record shows a succession of Jurassic continental deposits overlaid by Cretaceous sediments, both calcareous and siliciclastics, are of transitional to marine origin. The Paleogene sequence is made up of siliciclastic rocks deposited mainly under continental condition with some marine influence. Three major deformational phases are presents in the basin; rifting, thrusting and wrenching, responsible for all type of trap geometries.

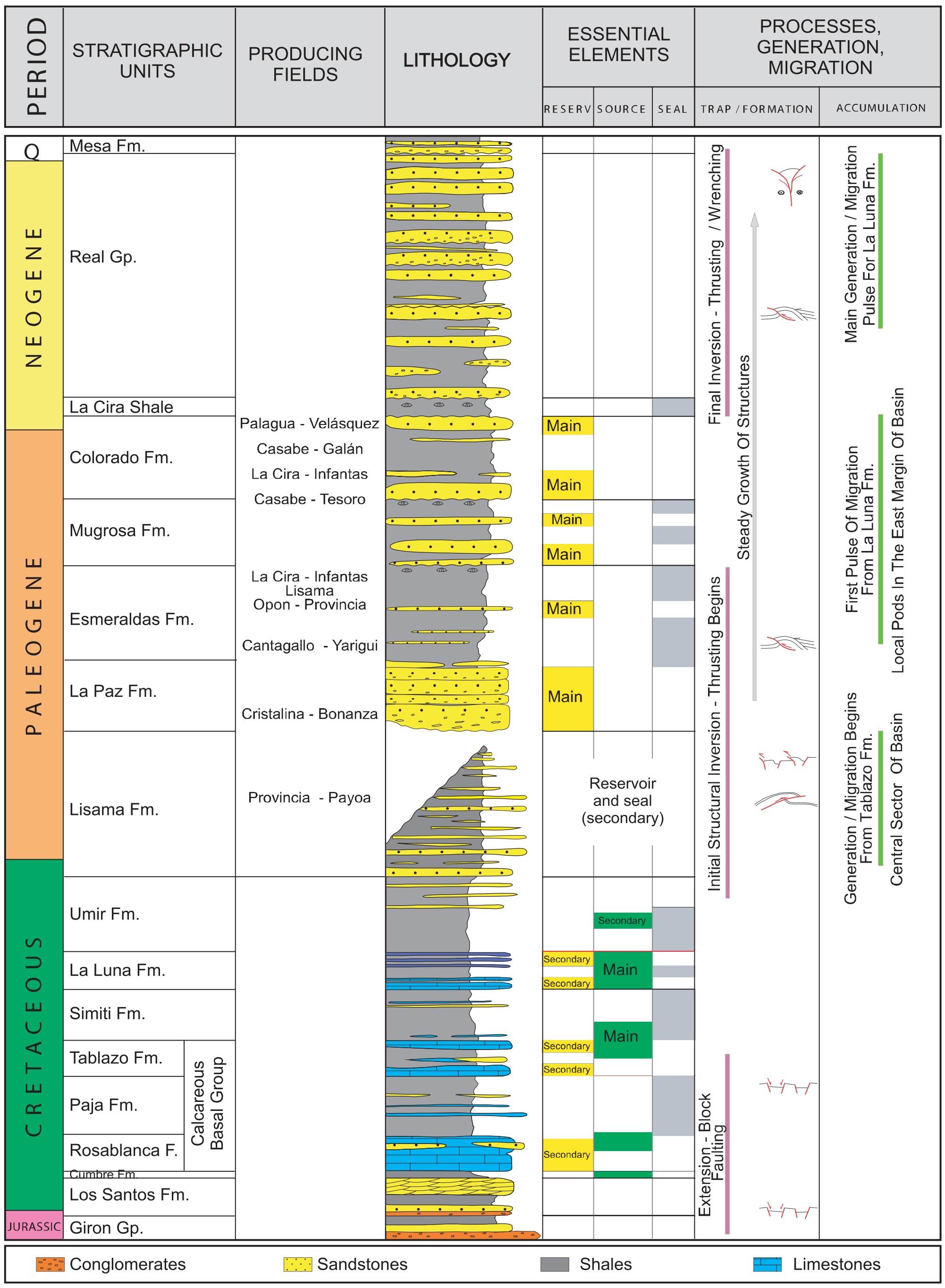

Figure 35. *Middle Magdalena Valley Basin Petroleum system chart.*

Petroleum Geology (Figure 35)

- **Hydrocarbon evidence**

A century of exploration history in the basin has lead to the discovery of about 1,900 MMBO, 2.5 TCF and a total of 41 fields, including the first giant in Colombia, La Cira-Infantas field.

- **Source**

Cretaceous Limestones and shales of the La Luna and the Simiti-Tablazo formations are the main source rocks in the basin. TOC are high (1-6%) and organic matter is essential type II, Ro reach values of 0.6 -1.2 %. The main source rocks were deposited during two worldwide anoxic events.

- **Migration**

The Eocene unconformity separates the primary reservoir from the underlying active source rocks, forming an ideal a plumbing system for the migration of petroleum. Major migration pathways consist of: 1) Direct vertical migration where La Luna sub-crops the Eocene unconformity 2) Lateral migration along the Eocene sandstone carrier 3) Vertical migration via faults in areas where the La Luna does not sub-crop the Eocene unconformity. Critical period occurs during the Upper Neogene, about 5 Ma. , and continue locally today.

- **Reservoir**

97% of the proven oil in the basin comes from continental Paleogene sandstones (Paleocene-Miocene), Lisama, Esmeraldas-La Paz, and Colorado-Mugrosa formations, with average porosities 15-20% and average permeabilities 20-600 md. Lightly explored reservoirs are fractured systems of the Cretaceous Limestones Basal Limestone Group and La Luna Formation.

- **Seal**

The seals for Paleogene sandstone reservoirs consist of interbedded non marine ductile claystones, mainly from the Esmeraldas and Colorado formations. The seals for potential Cretaceous limestone reservoirs are marine shales of the Simiti and Umir formations.

- **Trap**

Exploration has been directed to prospecting accumulations in structural closures form by major asymmetric anticlines, among them:

1) Contractional fault-related folds hidden beneath surface thrust, 2) duplex structures with fault independent closure, 3) fault-dependent closures in which reservoir strata dip away from the fault, 4) very important; traps in the low side of sealing faults.

- **Prospectivity**

The Middle Magdalena Basin is one of the most explored basin of Colombia where 41 fields have been discovered on Paleogene deposits. Surprisingly it still contains one of the most prolific areas yet to be explored: the Cretaceous carbonate plays.

Potential exploration areas are mainly related to inverted normal faults and subthrust anticlines. Subtle stratigraphic traps associated with Miocene-Upper Eocene onlaps, incised channels and truncations are also major objectives for future exploration.

3.13 Sinú-San Jacinto

Basin type	Accretionary Prism
Area	38,500 km2 9,500,000 acres
Discovered reserves	Marginal
Oil field discoveries	Non commercial
Wildcat wells	44
Source rocks	Cansona Formation
Reservoir rocks	Paleogene sandstones
Seal rocks	Floresanto Formation

Overview

The Sinú - San Jacinto Basin/foldbelt was formed as an accretionary prism along the South American continental margin due to subduction of the Caribbean Plate. The San Jacinto Fold Belt was developed in the Eocene and consists mainly of sedimentary rocks and slivers of volcanic rocks scrapped off the Caribbean Plate. The Sinú belt is younger and consists mainly of sedimentary deposits along the northwestern margin of Colombia, incorporated later in the accretionary prism during the Miocene. Numerous oil and gas seeps are the evidence of a petroleum system at work. Clastic and carbonate potential reservoirs together with strong structuration indicate high prospectivity.

The enormous amount of oil seeps are evidence of hydrocarbon generation. Good siliciclastic reservoirs are present throughout the area sealed by the Floresanto shaly facies.

Petroleum Geology (Figure 36)

- **Source**

Hydrocarbon generation began in the Miocene, but some earlier generation could have occurred in the Cretaceous (Cansona Formation). The enormous amount of oil seeps are evidence of hydrocarbon generation in the region. The Cansona Formation is favorable for the generation of liquid hydrocarbons and consists mainly of organic rich kerogen types I-II. The Porquero and Floresanto formations and the muddy facies of the Cienaga de Oro Formation frequently show a gas prone signature with type II, III kerogen.

- **Migration**

Migration of hydrocarbon along fractures is documented by the abundant oil and gas seeps.

Sinú-San Jacinto

- **Reservoir**

The main potential reservoirs are siliciclastics deposited during the Eocene - Miocene. These deposits vary from continental to fluvial-deltaic to marine and also include shallow water carbonate deposits.

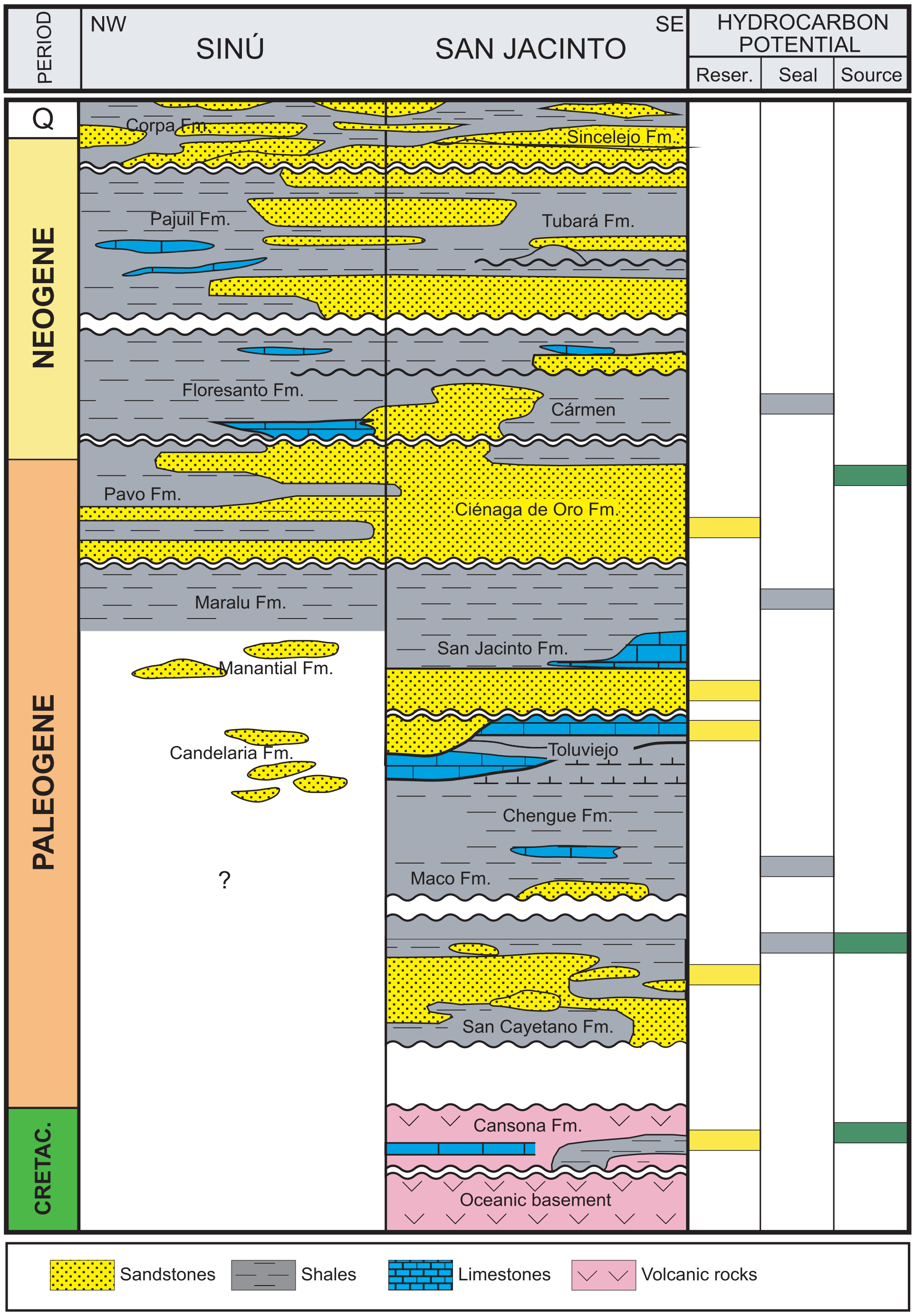

Figure 36. *Sinú – San Jacinto Basin Petroleum system chart.*

- **Seal**

Overlapping sealing units are present in the entire basin. The seals are associated with translapping or migration of facies changes from marine to continental environments.

- **Trap**

It is possible to identify different kind of plays with good exploratory potential; structural traps in thrust-related closures and stratigraphic traps present at the northern and of the San Jacinto fold belt. Shale-diapirs flanks could also be exploration targets.

- **Prospectivity**

Abundant oil and gas shows, clastic and carbonate potential reservoirs, together with strong structuration indicate high prospectivity.

3.14 Sinú Offshore

Basin type	Accretionary Prism
Discovered reserves	None
Wildcat wells	

Basin Overview

The Sinú Offshore area lies in the coastal waters of northwest Colombia. It extends from the mouth of the Magdalena River in the northeast to the northern end of the Urabá Gulf in the southwest. Water depth over almost all of the area is less than 1.200 meters. Approximately, two thirds of the area is shoreward of shelf break that roughly parallels the coast. The remaining third consists of shallow water with depth on the range from zero to ca. 200 meters.

The Sinú Offshore is juxtaposed to the west margin of the Sinú-San Jacinto Basin/Foldbelt (onshore) a structurally prospective area that include at least two genetically distinct packages of sedimentary rocks

Petroleum Geology

- **Source**

The principal likely source for thermogenic hydrocarbons in the Sinú Offshore domain are Cenozoic marine condensed sections and prodelta shales. In addition, there are strong evidences in the adjacent onshore area for the presence of an Upper Cretaceous source that could have a lateral equivalent in the offshore area. This statement is supported by geochemical analyses done in onshore oil seeps that relate then to the Cretaceous La Luna source rock.

- **Generation and Migration**

Active generation and migration is based on the occurrence of: 1) Numerous shows of gas in nearly all of the offshore wells. 2) Several flowing oil and thermogenic gas in the nearby onshore area. 3) Traces of oil found in the San Bernardo-IX well. 4) Evidence of thermogenic hydrocarbons in extracts from nine piston core samples, collected by British Petroleum. 5) The existence of a Cretaceous oil prone generative system remains hypothetical

- **Reservoir**

The basin contains sandstones that are potential reservoirs. Presence of fine-grained sandstone has been documented by several wells drilled in the area. A few wells have reported the existence of segments composed of coarse grained sandstone. Large accumulation of sandstone turbidites are expected against the flanks of shale diapirs.

- **Seal**

Sealing units occurs throughout the basin and they consist of shales deposited in prodelta environments. The flank of diapirs could act as good lateral seal. However, the seal prospect efficiency appears to be a critical point for the prospectivity in this area.

- **Trap**

The size of the traps is large and most of them lie at a depth of 1 to 2.5 seconds two-way-time on seismic. Thrust-related anticline traps with primary objectives of Oligocene low-stand sandstone are the main targets. In addition, several large combination traps formed by sin-tectonic onlaps of Miocene sandstone, structural traps on the flanks of shale piercement-diapirs, low-side roll-overs of Pliocene sandstone involved in listric normal faults and pure stratigraphic traps, form the bulk of exploration opportunities in the area.

- **Prospectivity**

The area covering the Sinú Offshore domain is prospective because there are numerous structural and stratigraphic plays. These plays are supported by adequate source rock, siliciclastic reservoirs and active generation and migration of hydrocarbons. The presence of large quantities of liquid hydrocarbons remains hypothetical.

3.15 Upper Magdalena Valley

Basin type	Poly-historic, rift shoulder to broken foreland
Area	26,200 km2 / 6,474,000 acres
Discovered oil reserves	631 MBO
Discovered gas reserves	123 GCF
Wildcat wells	210
Discovered fields	36

Overview

The Upper Magdalena Valley Basin of Colombia is a Neogene Broken Foreland Basin that evolved from a larger collision-related Paleogene foreland basin which extends to the east as far as the Guyana Shield. The basin has an area extend of about 26,200 km2. It is bounded on both sides by Precambrian to Jurassic basement uplifts that define the flanks of the Eastern and Central Cordillera.

The basin contains a Cretaceous sequence that started with continental deposits followed by a transgressive sequence composed of shales and limestones, overlaid by the Caballos sandstone unit, which is one of the main reservoirs in the basin.

These units are followed by a sequence of limestones, shales, and cherts of Albian to Campanian age. Two levels of organic rich source rocks of middle Albian and Turonian age provide the source of hydrocarbon for all accumulations in the basin.

This sequence is overlaid by the Campanian to Maastrichtian Monserrate Formation composed mainly of sandstones. This unit is also an important hydrocarbon reservoir.

The Cenozoic sequence deposited during the two collisional events that built the present day sedimentary basins in Colombia is entirely non-marine and contains Paleogene and Neogene molasses.

Petroleum Geology

- **Hydrocarbon Evidence**

Currently, the Upper Magdalena Basin is producing 18 million barrels of oil per year from 28 fields. Numerous oil seeps abound in the basin.

- **Source**

Two worldwide anoxic events of Middle Albian and Turonian age are responsible for the deposition of shales and limestones with high organic content in the Tetúan, Bambucá and La Luna formations. The predominant kerogen is type II. They contain on average 1%-4% of T.O.C. and Hydrogen index varies between 100-650 mgHc/gc.

- **Migration**

Migration starts soon after the first contractional event of Late Cretaceous age and continues through today. Remigration to present day traps start during Miocene, after deposition of thick molassic deposits.

- **Reservoir**

Three main reservoirs are distributed in the basin. The Cretaceous Caballos and Monserrate formations and the Miocene Honda Formation, all produce from sandstone reservoirs. High reservoir potential exists in fractured carbonates. A sandy facies in the Tetúan Fm. is a new objective for exploration; which nowadays produces in one oil filed.

- **Seal**

Top and lateral seals are provided by a very thick sequence of plastic claystone of the Bambuca, Guaduala and Honda formations of Cretaceous to Neogene age. Preservation is good for the Caballos sandstone, but fair to poor for Monserrate reservoir.

- **Trap**

Structures like fault-bend fold anticlines, sub-thrust and sub-basement closures, imbricate fans, back-thrust and wrench related anticlines in both sides of the basin are all prospective. Exploration potential also exists in several types of stratigraphic traps. Trap formation began in late Cretaceous and ended by late Neogene. Time of initial trap formation is documented by the presence of growth strata of Maastrichtian age.

- **Prospectivity**

During the last two decades the basin has been actively explored for hydrocarbon. However, it is believed that important oil reserves remain trapped in stratigraphic and sub-thrust plays. The addition of new reserves will be linked to the development of new and maybe unconventional play concepts. More than 546 MMBO reserves have been found to date in 28 oil fields.

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